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STOP AND INCREASIN..(U) BULOVA SYSTEMS AND INSTRUMENTS
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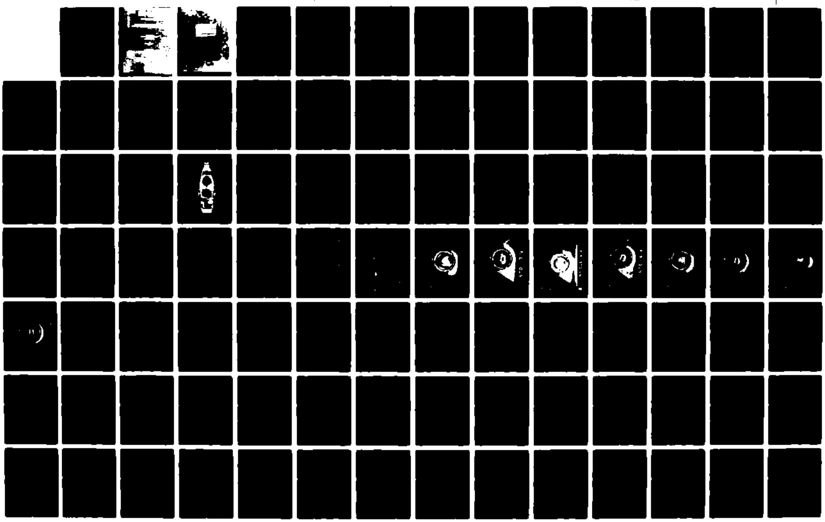

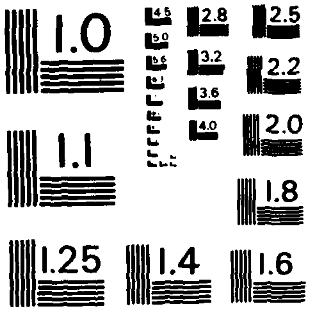
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The object of task 1 (to reduce production costs by simplifying the timer stop) was accomplished by replacing the tumbler stop with a threaded sleeve at an estimated saving of $0.176 to $0.220 (per unit).

In conjunction with the development of the sleeve for the simplified stop system, the modification of the trigger and lower fuze body was investigated to improve structural support during high-g setback. Incorporation of these

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20. ABSTRACT (cont)

modifications with the revised stop system would result in a combined cost saving of $0.150 to $0.194 per unit.

Task 2 focused on reducing production fallout by increasing timer torque. A bridled mainspring with improved characteristics at the 100- to 200-second range of timer operation was designed, but the resulting 70% increase in cost could not be justified. A further effort at improving torque transmission (treating the gear train with Emralon) proved ineffective in that it did not improve the performance of the timer.

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INTRODUCTION

This report summarizes the works performed by Bulova Systems and Instruments Corp. (BSIC) on a product improvement program for ARRADCOM under the contract #DAAK10-81-C-0067 Task 1 and Task 2. The objective of this program aimed at reducing the cost and enhancing the productivity of the M577 MTSQ Fuze by (1) replacing the tumbler stop system of the timer by a simpler system, and (2) increasing torque available to the timer to reduce production line fallout.

The timer stop system is used to provide a positive stop at the setting limits ▲94 (shipping) and at 200 seconds to preclude the firing arm follower from damaging of the timing scroll and/or cause setting errors. The current design is a tumbler system which is replaced by a simpler design including a track, threaded in the inner wall of the sleeve, with a vertical follower linking the timer package. The new design shall provide the same functional characteristics and operational safety.

The performance of the timer is dependent on the supplied torque. Available torque to the timer will be increased by reducing the friction in the gear train and improving the mainspring torque output. Lubrication of gear train is investigated and the mainspring is modified to provide a more consistent torque over the operating range of the fuze.

SUMMARY OF THE ACCOMPLISHMENTS

For Task 1, a threaded sleeve timer stop system was designed. The design applied the track-and-follower idea by running a tab follower in a threaded track having a number of threads conformal to the revolutions of timer package over the operating time range. The follower links the rotation of the timer package for positive stops at the ends of the track. The function of the mechanism was tested and evaluated. Material and fabrication of parts were investigated for structural integrity and cost benefits.

For structural compatibility of parts the investigation consisted of theoretical analysis and a series of laboratory tests, and a marginal condition was found in sleeve under high g setback. Evaluations were performed on various ways of improving sleeve strength, including design configuration, heat-treatment and alternative materials, with no marked improvement; however a modified trigger assembly was developed with an associated change of the lower fuze body to distribute the setback load of the three-module assembly onto the fuze body rather than suspended on the flange of the sleeve.

Two engineering approaches were proposed for Task 2. The first was increasing the gear train efficiencies for torque transmission and the second was improving mainspring torque output. The first approach started with a computer program performed to analyse possible parameters that affected the point efficiency and cycle efficiency of meshing gears. The results indicated that torque transmission efficiency could be increased by reducing the friction coefficient of gear surfaces. A lubricating process was proposed and evaluated, which included coating the gear train components with dry lubricant film of brand name "Emralon" to reduce surface friction. Test results concluded that this process did not improve timer performance.

The second approach was the modification of the mainspring. A "Bridled" spring design was obtained. A test program was conducted to evaluate the mainspring of two different configurations: (1) spring with VYDAX coating and (2) spring with both VYDAX coating and Bridle. The test result showed that the bridled mainspring had higher torque efficiency and more stable output than regular mainspring, and superior characteristics at the 100 to 200 seconds range of timer operation at higher spin rate.

The modified timer stop and the bridled mainspring passed all qualification tests. Cost evaluations estimated that the unit cost savings for threaded sleeve stop alone was \$0.220; and, for combination of threaded sleeve stop and modified trigger assembly was \$0.194. The bridled mainspring incurred 70% higher part cost than regular mainspring.

TASK I. REPLACE TUMBLER STOP SYSTEM WITH A SIMPLER SYSTEM

INTRODUCTION

Based on the original proposal for document DAAK10-80-R-0252 BSIC redesign the multi-turn timer stop by using a track-and-follower to replace the tumbler stop system. The track is built in the sleeve in the form of internal thread, allowing a controlled displacement for a follower which links the rotation of timer package. The new de[illegible] is referred to as threaded-sleeve timer stop.

DESIGN MODIFICATION

FUNCTION OF THE TIMER STOP

The stop system provides a positive stop to setting fuze between a shipping position at ▲ 94 and a maximum functioning time of 200 seconds. This stop system is applied directly to the Fuze Timer Assembly which is turned during the fuze setting operation. One full rotation of the Timer Assembly corresponds to a change of 50 seconds in the fuze setting. ▲ 94 corresponds to a setting of (-6) seconds, so that the required setting range is approximately 200 - (-6) = 206 seconds. And this setting range corresponds to 206/50 = 4.12 rotations of the Fuze Timer Assembly. The stop system is required to prevent motion beyond each end of this range.

The main feature of the modified timer stop is the sleeve which is machined with an internal thread of six turns. A tab follower keyed to a slot in the outer wall of the barrel housing, which is allowed to slide up and down. The follower having a protrusion meshes with the thread and counts the rotations when the Timer Assembly is rotating. Two stop pins are pressed into the thread, to permit 4.12 turns of running track for the follower. The upper stop pin stops the follower at the timer setting of 200 seconds, while the lower pin stops at ▲ 94.

DESCRIPTION OF THREADED-SLEEVE STOP

The new stop system consists of three new parts and five modified parts. New parts are follower, upper stop pin and lower stop pin; modifications are made on sleeve, barrel housing and mainspring barrel. Also, a spacer is obtained by modifying the internal tab tumbler, and a washer is similar to the tumbler keeper. The arrangement is illustrated in Figures 1 and 2.

Sleeve, Upper Stop Pin, Lower Stop Pin

The sleeve maintains most features of the regular part configuration. It is modified by adding an internal thread of 6 turns 1.5625-18 UNEF, left hand. Two pin holes are pre-drilled for the stop pins. They are located in the thread so that when the pins are pressed in, the upper stop pin blocks completely the top full thread and the lower stop pin blocks the bottom full thread, leaving 4.12 turns clear track in between for the follower. Same as the regular unit, the sleeve will be made from aluminum die forging of alloy 2014-T6, but the wall thickness of the die forging is modified to allow machining the thread in inner wall.

Both stop pins are made of hardened tool steel. They are shaped to right angle of unequal legs with rectangular cross section. The shorter leg is pressed into the thread to provide the stop and the longer leg embeds the outer flange of the sleeve for security. The upper stop pin is also used as sleeve key to ogive.

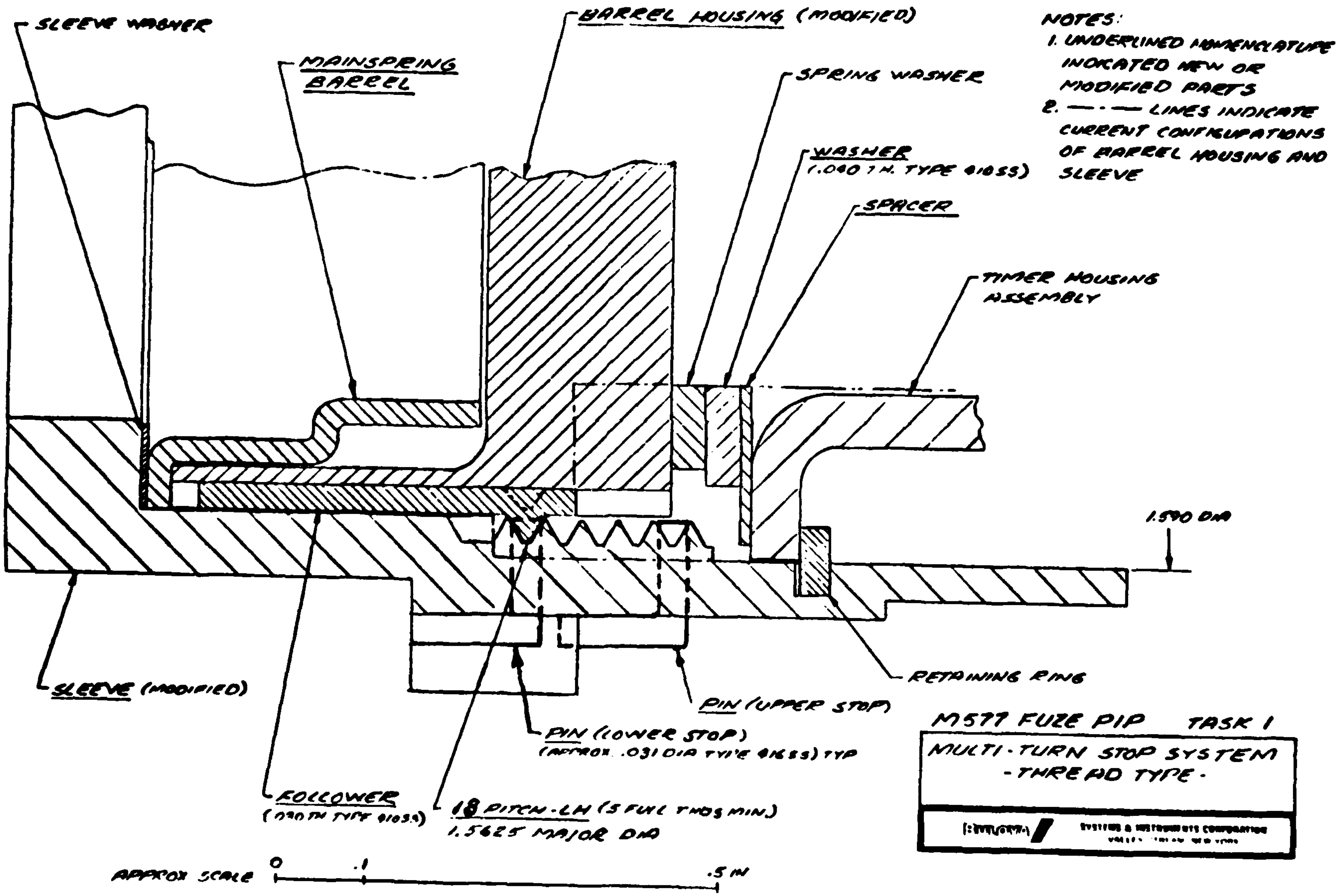


FIGURE 1. MULTI-TURN STOP SYSTEM--THREAD TYPE

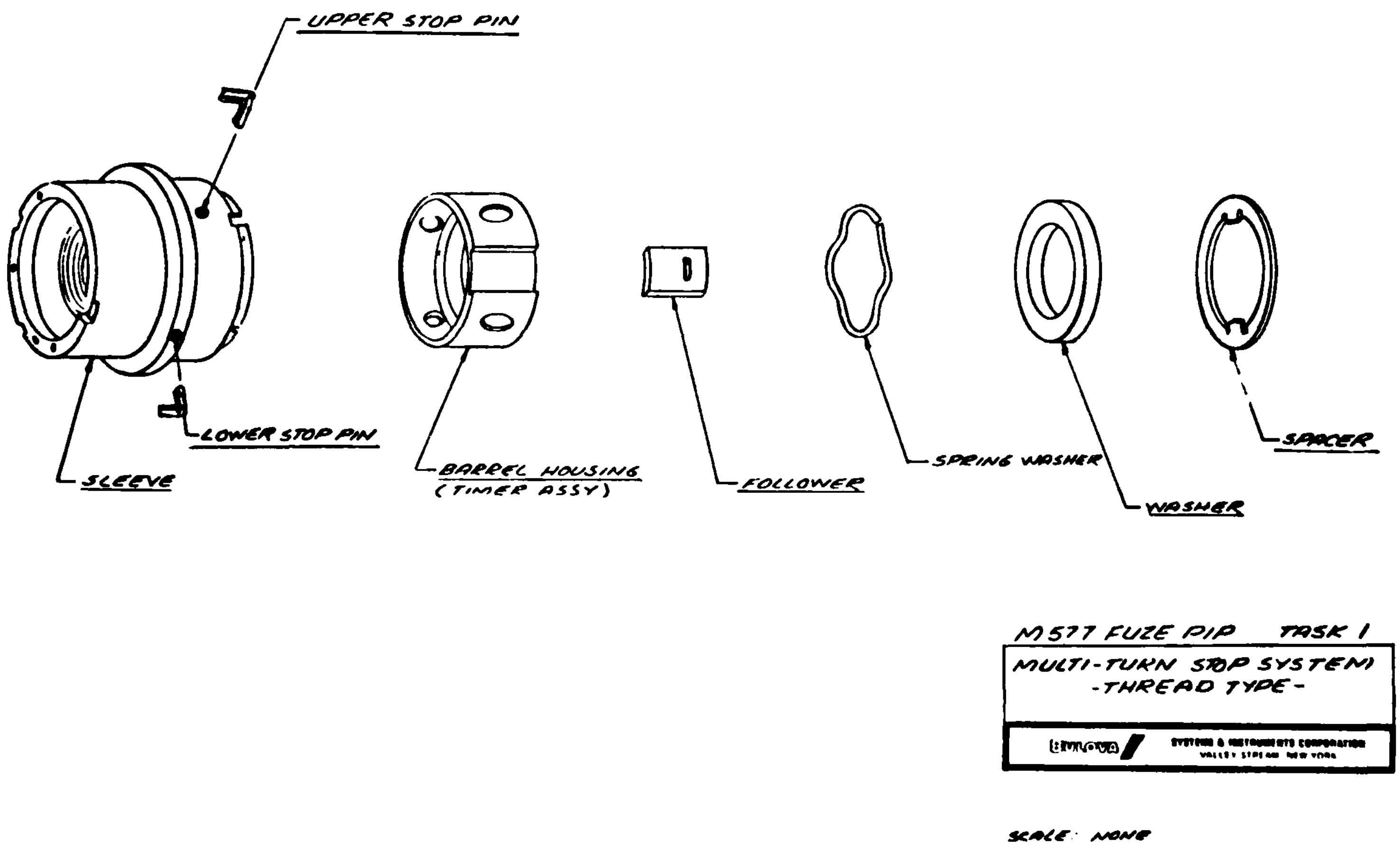


FIGURE 2. MULTI-TURN STOP SYSTEM--THREAD TYPE (EXPLODED VIEW)

Barrel Housing, Mainspring Barrel

Barrel housing is machine finished from a stainless steel flat-end cup blank. An axial groove is milled in the outer wall as the seating for the follower which functions as a slide key and retains the barrel housing laterally when it is stopped by either pin. All other features of the regular barrel housing remained in the modified part.

The mainspring barrel has a minor modification. A cutout at the flange is provided to allow the follower sliding in the barrel housing groove at assembly.

Follower

The follower is the key link of the stop system. It is a stainless steel tab, .187 wide x .350 long x .036 thick. A single tooth is formed on one side, which matches the internal thread of the sleeve. Meshing with the thread the follower has a free moving interval of 4.12 turns. At stop situation, the follower withholds the setting torque to retain the timer from turning beyond the limited settings, ▲ 94 for shipping, and 200 second for maximum function. The setting torque develops a tangential force to the tooth of the follower.

The maximum setting torque on the timer setting shaft is 13 in-lb (when torque exceeds this value, the grip-ring clutch slips). The minimum torque required to set the timer is 5 in-lb (for overcoming the package frictional force). In determining the maximum force applied to the tooth on the follower, the setting friction torque has been neglected; therefore with a 5 to 1 ratio speed reduction gear train, the torque is increased to 13 x 5 = 65 in-lb. With a moment arm of approximately .75 inches (radius of sleeve inner wall), the tangential force developed by the torque on the tooth is then 65 ÷ .75 = 86.7 lb. The tooth of the follower is required to withhold this force for a positive stop of the timer. Following are mathematical analyses of the safety of critical parts.

A) The sectional area of the tooth at the root is, by design, $.036 \times .187 = .0067$ square inches. The shear stress on the tooth is

$$\tau_1 = \frac{86.7}{.0067} = 13,000 \text{ psi}$$

The follower material (S. S. 310) has an ultimate strength of 95,000 psi. The shear strength is approximately 75% of this value, i.e.,

$$95,000 \times 75\% = 71,250 \text{ psi}$$

Minimum depth of tooth engagement with stop pin:

Dimensional analysis on the stop mechanism design obtained that in case all parts' tolerances were reducing the stop engagement, the minimum depth of tooth engagement with stop pin was .016 (full tooth depth is .032 min.), the stressed sectional area was then .0033 square inches. The shear stress on the tooth was

$$\tau_2 = \frac{86.7}{.0033} = 26,300 \text{ psi}$$

comparing with shear strength 71,250 psi, the factor of safety was 2.7.

B) The stop pin has a minimum bearing surface of .0069 square inch (.095 wide x .073 long sleeve wall) in the sleeve, the compressive stress on the bearing surface is

$$\frac{\text{force}}{\text{area}} = \frac{86.7}{.0069} = 12,565 \text{ psi}$$

(Note that the stop pin is rigidly embedded in the sleeve.) The sleeve material has a yield strength of 60,000 psi. The factor of safety of stop pin bearing is over 4.7.

DEVELOPMENT OF THREADED SLEEVE STOP

The threaded sleeve stop is developed from the original proposal for document DAAK10-80-R-0252. Models have been built to demonstrate the feasibility of the idea. Improvement and redesign have been made from time to time to achieve a reproducible prototype for the objective of the Product Improvement program.

The initial model had a sleeve with internal thread 1.5625-24 LH, and a follower having a single male thread to match with. This model demonstrated the cam-and-track function of the system. It also revealed the running difficulties of the follower in the fine thread of 24 pitch.

The sleeve thread was then redesigned to 1.5625-18 LH. A second model was built with a curved follower to match the thread diameter. The follower and its seating were shaped in a dovetail to retain the follower. Stop pins were made of stainless steel. All parts were machine finished. The model was functionally tested. It showed that the stop held the timer at the limited setting until the grip ring clutch slipped. The slipping torque was*15.5 in-lb at ▲ 94 stop and*13.5 in-lb at 200 seconds stop. Model test discovered that the dovetail shape was not necessary for the follower. It only created difficulty for assembly operation. The stop pins were found slightly deformed at high setting torque.

Designs were revised to eliminate unnecessary part features for expediting production. A flat follower of straight edges was obtained by sheet metal stamping. Washer and spacer were also made of stamped parts. Stop pins were made of hardened steel to prevent deflection. Prototypes of the revised design were fabricated. A laboratory test was conducted to prove the function of the stops. The test consisted of two parts: a slip test and a destructive test. Slip test showed that the lower stop pin retained the timer at ▲ 94 until the grip-ring clutch slipped at the torque of *16 in-lb. The upper stop pin retained the timer at 200 seconds for clutch slipping happened at *13 in-lb. Destructive test was performed by applying 28 in-lb to the setting shaft, on the lower stop, with the clutch disabled. The frictional force torqued the timer 8 in-lb. The net torque on timer was 28-8 = 20 in-lb. This torque developed a tangential force on the follower:

$$20 \times 5 \div .75 = 133.34 \text{ lb.}$$

The timer setting crept 0.3 second from 93.8 to 93.5, corresponding to an angular displacement of timer 2.16°. The timer scroll track has a clearance of 4.8° to 7.8° at this end. Then applied 24 in-lb to torque the upper stop pin which developed a force on the follower

$$(24 - 8) \times 5 \div .75 = 106.67 \text{ lb.}$$

The timer setting shifted 0.4 second from 200.0 to 200.4, corresponding to a timer displacement of 2.88°. The scroll track has a clearance of 52° to 55° at this end. The timer was safe.

These destructive forces exceeded the possibly maximum force that the stops might encounter, which was derived in paragraph 3.2.2 to be 86.7 lb in the worst case. For description of test procedure see Appendix A.

*Slip torques of grip - ring clutch were not pre-regulated for test samples.

EVALUATION OF THE STRENGTH OF THE SLEEVE

Internal thread in the sleeve reduces the wall thickness, consequently decreases the strength of the sleeve. The theoretical strength of a threaded sleeve can be calculated as below:

internal thread: 1.5625 - 18 UNEF

major diameter = 1.563 inches

outside diameter of the sleeve = 1.646 inches minimum

The minimum sectional area of the sleeve is

$$A = \frac{\pi}{4} (1.646^2 - 1.563^2) = .209 \text{ sq. in.}$$

Material of the sleeve is aluminum alloy 2014-T6 having a tensile strength of 70,000 psi. The sleeve can withstand a load of

$$.209 \times 70,000 = 14,630 \text{ lb.}$$

Setback force on the sleeve: - Figure 3 illustrates the sleeve loaded by the weight of the three - module assembly. The total weights of Counter, Timer Assembly, the base step of Sleeve (free body) and Trigger Assembly come up to .527 lb. average. This weight is supported by the base of the sleeve. At setback, it exerts a force which is equal to the product of its value and the value of "g" (i.e., .527 g).

This force stresses the lower portion of the sleeve (in Figure 3, this portion is shown .310 long). The sleeve is elongated. Aluminum alloy 2014-T6 has an elongation of 13% in 2 inches. If this value applies to the lower portionof the sleeve, the maximum elongation of the sleeve is then .310 x 13% = .040 inch, which is less than the clearance between Timer Housing Key and the bottom of slots in the upper sleeve (.046 to .050 as shown in Figure 3). Therefore, before the sleeve fractures, total setback force by the three-module assembly is acting on the base step of the sleeve and is stressing the lower portion. For a sleeve strength of 14,630 lb., the sleeve can withstand a setback force of

$$14,630 \div .527 = 27,760 \text{ g}$$

A static load test and an air gun test were conducted to verify the strength of the sleeve. Samples to be tested were machined to provide a groove in the inner wall to simulate the thread-relief. The static load test consisted a test group of five units and a control group of four units. A Tinius Olsen tester was used. Test results are listed in Table 1.

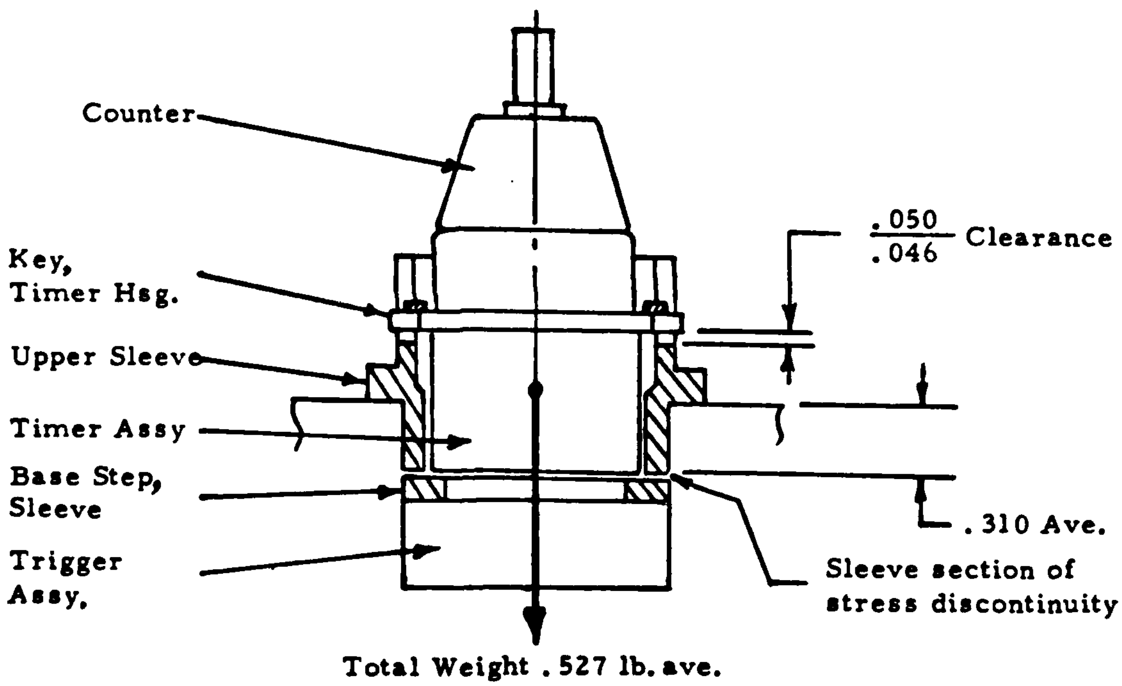


Figure 3. Sleeve Loading

Table 1. Static Load Test Standard Sleeve

	Test Group	Control Group
Ave. Rupture point, lb. force	14, 610	14, 518
Standard deviation	423	1, 284

Inspection on tested units found that four out of five test-samples fractured at the groove, and the remaining one fractured at the base-fillet; All four control-samples fractured at the base-fillet. A section view of the test sample is shown in Figure 4.

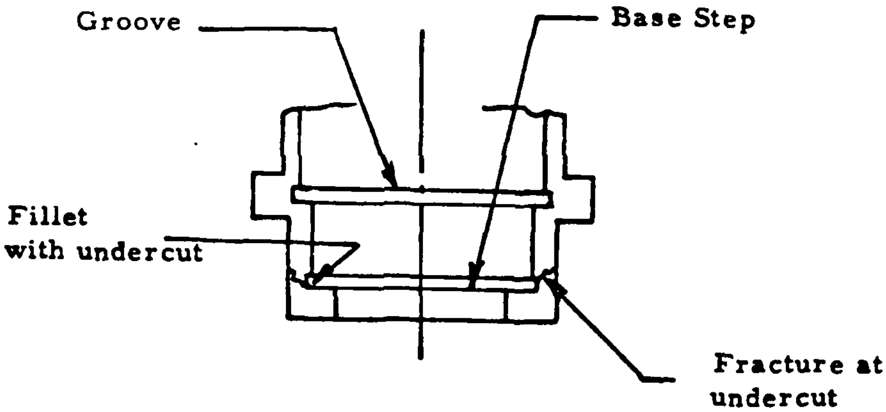


Figure 4. Fracture of Sleeve

The air gun test consisted a test group of seven samples and a control group of four samples. After test, three test-samples and one control-sample which were tested below 25, 466 g were found intact. One test-sample tested at 27, 182 g was also intact. Cracks in sleeves were observed in two test-samples and three control-samples, which were tested between 25, 531 g and 31, 192 g . All cracks happened at the base-fillet. One test-sample fractured at 31, 542 g , with base separated from the sleeve body. For detail descriptions, see Appendix E 1.

These tests showed that:

1. The strength of test-samples (sleeves with groove simulating internal thread-relief) conformed or closed to the theoretical strength of threaded sleeve, 14, 630 lb. force of static load, or 27, 760 g of setback force.

2. Most of the structural failures happened below 30, 000 g, at the base-fillet of sleeve where was a section of stress concentration and stress discontinuity.

EVALUATION OF PROPOSALS FOR IMPROVEMENT OF SLEEVE-STRENGTH

Various engineering approaches were proposed and evaluated.

Sleeve Base-Fillet Configuration Redesign

Tests were conducted to evaluate the effects of base-fillet configuration on the strength of the sleeve. Three groups of samples were tested in the Tinius Olsen tester. They were: 1) sleeves having .005 inch deep undercut at the base-fillet, 2) sleeves having no undercut and 3) HTI sleeves machine finished with different tool. Complete test data were exhibited in a test report as shown in Appendix E2. The average rupture point of sleeves are listed in Table 2.

Table 2. Static Load Test Modified Sleeve

	Sleeve having undercut	Sleeve without undercut	HTI Sleeve
Ave. rupture point lb. force	13, 000	15, 573	15, 963
Standard deviation	1, 578	1, 109	523

Sleeves having undercut at the base-fillet fractured at lower forces. The undercut reduced sleeve-strength by twenty percent approximately. Removal of the undercut may increase the strength of the sleeve.

Sleeve Heat-treatment

Test samples were divided into two groups: One group was heat-treated at 350°F, 4 hours; another group was heat-treated at 450°F, 4 hours. Non heat-treated units were taken as control group. Evaluation consisted static-load tests and air gun tests. Summary of static-load test results are listed in Table 3.

Table 3. Static Load Test Heat-Treated Sleeve

	Heat-treated at 350°F	Heat-treated at 450°F	Non-heat-treated
Ave. BHN before heat-treatment	129.5	129.3	126
Ave. BHN after heat-treatment	127.5	116.3	-
Ave. rupture point lb. force	12,887	12,558	13,410
Standard deviation	606	2,287	

Heat-treatment did not improve the strength of sleeves. For detail test data. See Appendix E3.

Inspection on air gun tested units revealed that sleeves heat-treated at 350°F were intact at 21,750 g , but fractured at 30,601 g and 33,617 g . And those heat-treated at 450°F appeared slightly necked down and slightly distorted for 27,966 g and 29,088 g respectively, but one of the samples tested at 30,665 g was seriously distroted, and the SSD assembly was damaged. Complete description of air gun test was exhibited in Appendix E4.

Sleeves of Aluminum Alloy 7075-T6

Aluminum alloy 7075-T6 has higher strength than 2014-T6 (standard sleeve material). Air gun tests showed that sleeves made of 7075-T6 could withstand setback forces up to 27,000 g , without a trace of deflection.

But, at 30, 000 g tests, the survival rate of sleeve was about 60%. See Appendix E5.

Evaluation concluded that 1) Heat-treatment at 350° F and 450° F did not improve sleeve-strength. 2) Removal of undercut at the base-fillet of sleeve increased the strength by twenty percent. Yet the improvement had not met the requirement of 30, 000 g setback. 3) Sleeves of 7075- T6 appeared higher strength, but still had large percentage of failures at 30, 000 g level.

MODIFICATION OF TRIGGER ASSEMBLY

Evaluation of sleeve-strength found that modifications on the sleeve alone would not improve fuze-strength to meet the requirement of 30, 000 g setback. A design was proposed to modify the trigger assembly, which altered the distribution of setback force to the body, allowing the fuze functioning at higher g level. The modification involved two parts: the trigger spacer and the fuze body. The body was modified by replacing the tapered portion at the inner wall by a flat shoulder, which provided a support for the setback load exerted by the three-module assembly. The trigger spacer was extended with a rim protruding at the bottom end. This rim sits on the inner flat shoulder of the body as illustrated in Figure 5.

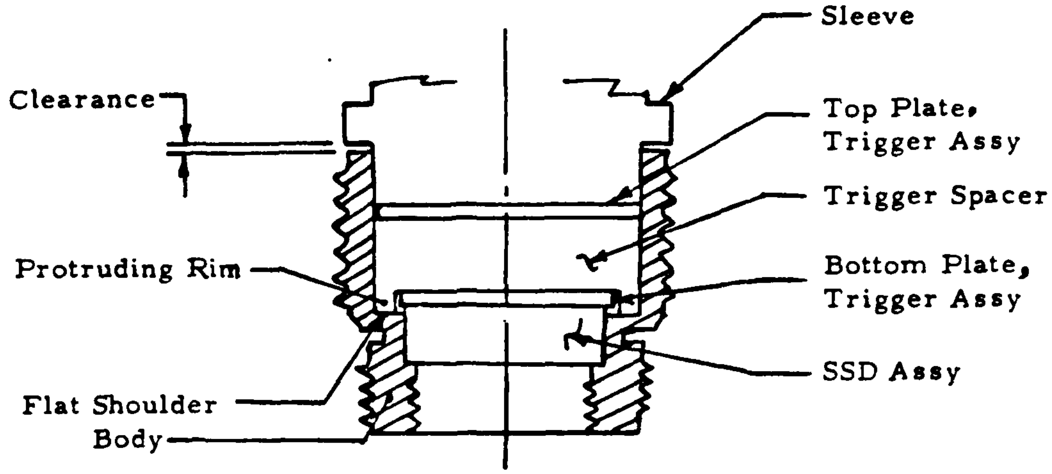


Figure 5. Modified Trigger Spacer

The protruding rim is an extension of the die-cast trigger spacer. It was 1/16 inch thick approximately, .090 inch high with an arc length about one half the periphery of the trigger spacer. The approximate section - area is

$$A = \frac{1}{2}\pi\,(\text{O.D.}) \times \frac{1}{16} = \frac{\pi}{2} \times 1.645 \times \frac{1}{16} = 0.161 \text{ sq. in.}$$

This sectional area supports the total weights of P. D. Housing Assembly and Three-Module Assembly with modified trigger, which is .570 lb. average. The setback force distributed in the sectional area, in the form of compression, is the product of the weight and the magnitude of "g". At 30,000 g., the compressive force is equal to .570 x 30,000 = 17,100 lb. force. The compressive stress in the rim is then

$$\sigma_c = \frac{17,100}{.161} = 106,000 \text{ psi}$$

Material of the trigger spacer is die cast aluminum SG-100A,

having: Ultimate strength = 46,000 psi

Modulus of elasticity E = 10.3×10^6

Elongation in 2 inches sample = 3.5%

Since the compressive stress σ_c is larger than the ultimate strength, a permanent deformation is resulted. The mode and value of the permanent deformation is dependent on the form factor, the plasticity-characteristics of alloy and the manner of force distribution. For simplicity, applying the formula of elastic deformation for a reference magnitude, we have

$$\delta = \frac{Fl}{AE} = \frac{17,100 \times .090}{.161 \times 10.3 \times 10^6} = .0009 \sim .001$$

The magnitude of elastic deformation is in the order of one thousandth of an inch. The maximum elongation of material is

$$.090 \times 3.5\% = .003$$

Comparing the elastic deformation (.001 inch) with the maximum material elongation (.003 inch) the structural integrity of the trigger spacer might not be affected.

TESTS CONDUCTED ON MODIFICATIONS

Fuze samples with Threaded Sleeve Timer Stop and Modified Trigger Assembly underwent laboratory and ballistic tests. The test procedures and results are described in the following sub-sections.

AIR GUN TEST OF FUZES WITH MODIFIED TRIGGER ASSEMBLY

Parts of Modified Trigger Assembly were obtained by rework of existing fuze parts, to simulate the design idea. Modifications were made on two parts: the trigger spacer and the fuze body. The trigger spacer was extended by pinning ring segments of aluminum alloy 2024-T4 to the die-cast to provide a support rim at the bottom end, and the fuze body inner wall was turned down at the tapered portion to form a flat shoulder to support the three-module assembly. A spacer was placed between the flat shoulder and the trigger spacer to maintain the longitudinal position of the three-module assembly. The modification is illustrated in Figure 6.

Air gun test was conducted on two demonstrative models. The test was performed at 30, 000 g's level. Complete test data are exhibited in Appendix E4. Table 4 lists the inspection results of tested units.

Table 4. Air Gun Test Data

S/N	Test Force "g"	After Test Inspection		
		Sleeve	Trigger	SSD Assembly
A	30, 474	Intact	intact & functioning	functioning, arming 1.07 sec.
B	30, 474	Intact	intact & functioning	functioning, arming 1.02 sec.

With Modified Trigger Assembly, after air gun test at 30, 474 g's, no structural failure of fuze parts was observed.

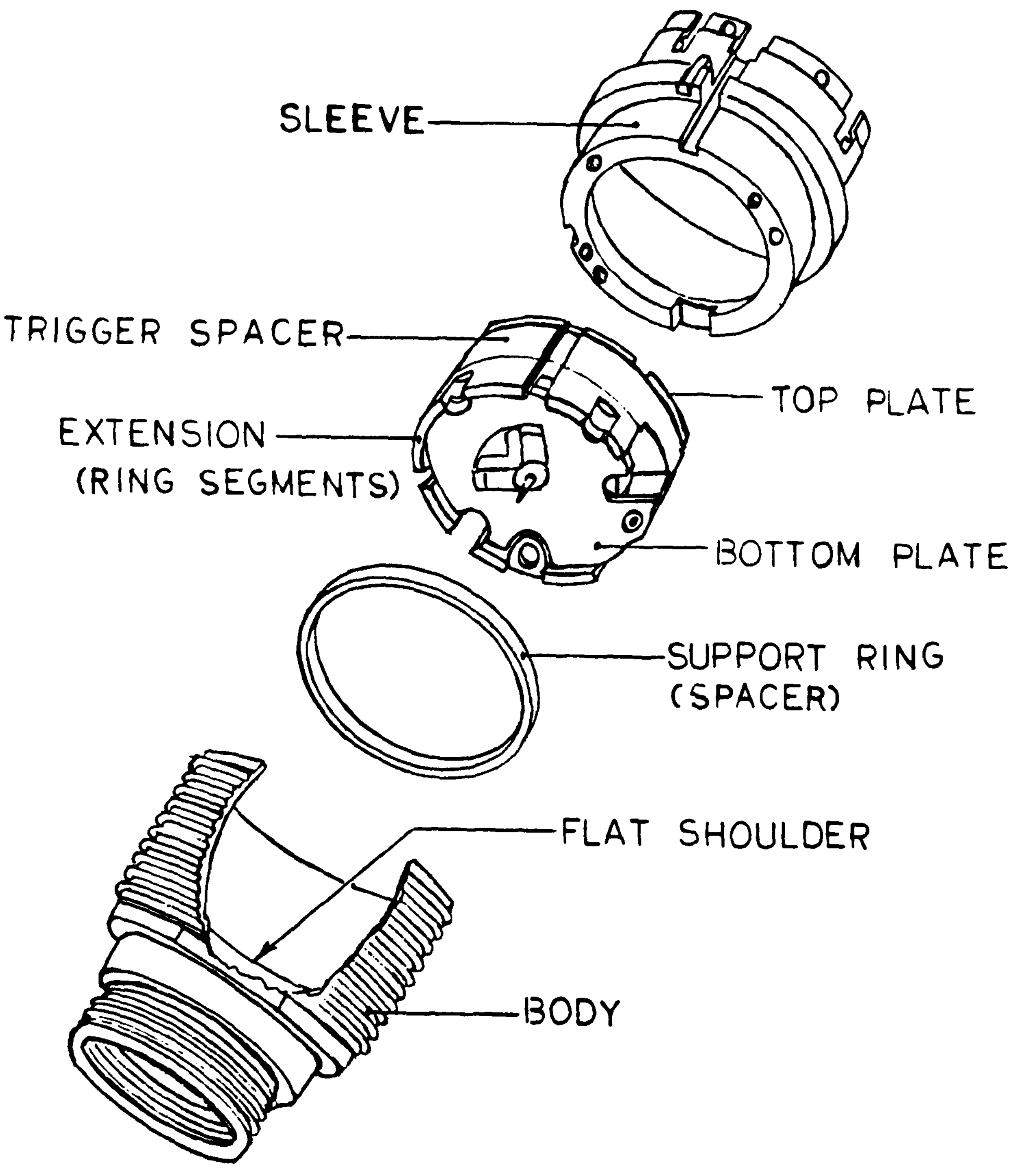


FIGURE 6. MODIFIED-TRIGGER TEST SAMPLE

BALLISTIC TESTS

The first ballistic test was conducted on fuze models with Modified Trigger Assembly. Test samples were divided into two groups, for different test conditions. One group was tested at 16,000 g , 100 seconds time setting; another group at 21,000 g , 75 seconds time setting. Test results are summarized in Table 5.

Table 5. Ballistic Test Data

Sample Size	Test Force g	Set Time sec.	Chrono Time sec.			
			n	$\bar{\bar{x}}$	σ	
10	16,000	100	10	100.056	.251	All functioning
10	21,000	75	8	74.912	.162	IFGI 1 outlier = 75.732

The second ballistic test was conducted on fuze models with both Threaded Sleeve Timer Stop and Modified Trigger Assembly. A cutaway view of the model is exhibited in Figure 7. Table 6 is the test summary.

MODEL TESTS

Five samples with Threaded Sleeve Timer Stop were tested for time setting range, timer setting torque (timer preloaded with spring washer), timer-stop holding torque and timer-stop holding force. Timer settings were made directly onto the setting shaft, without the grip-ring clutch, by means of a torque wrench. Time ranges were read from the fuze counter, and torques were read from the gage of the torque wrench. The values of timer-stop holding force can be derived by following procedures:

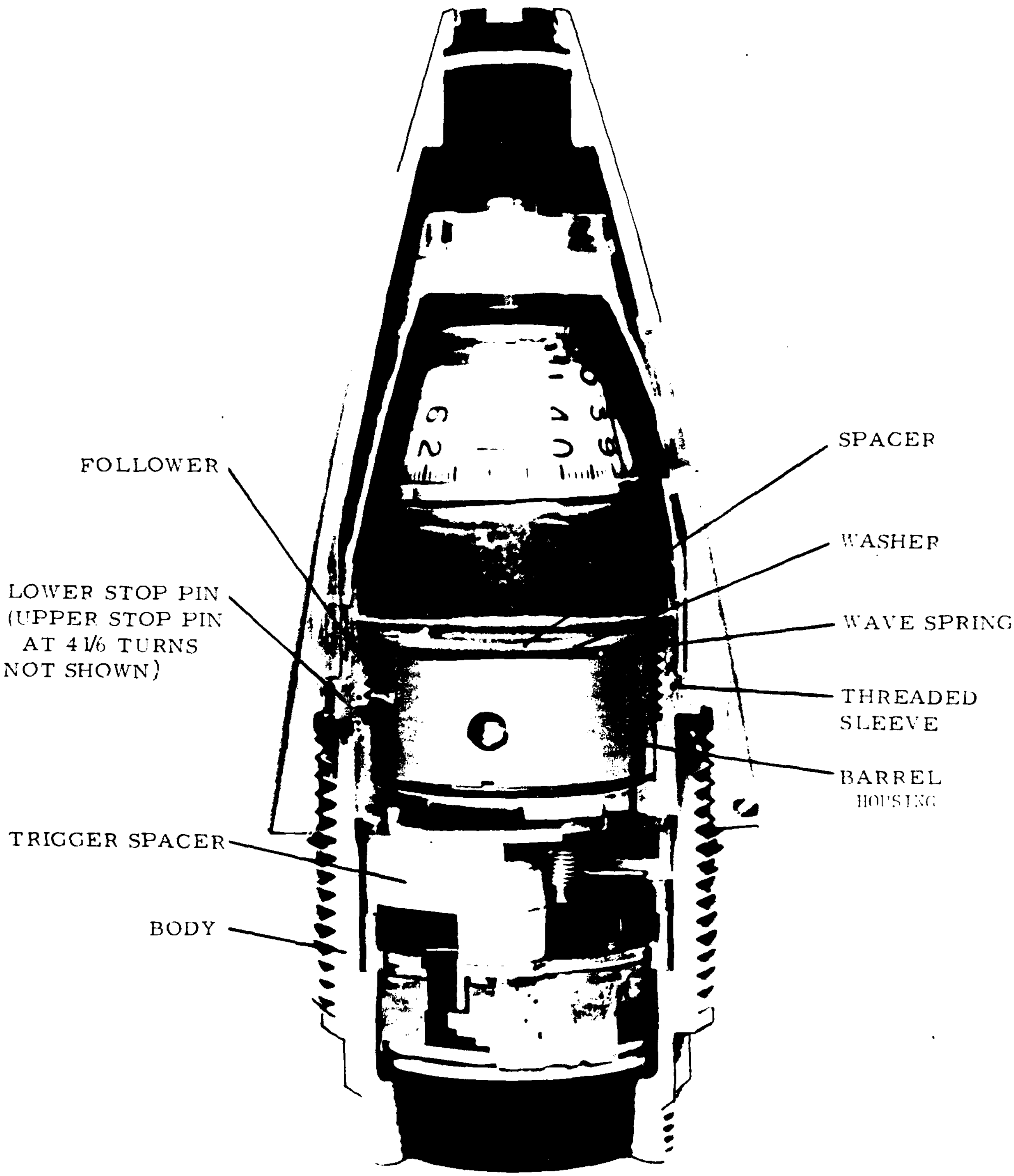


FIGURE 7. M577 PIP FUZE

Table 6. BALLISTIC TEST SUMMARY

TPR 2672 Supplement 5
Date of Test: Dec. 11, 1982

M577 PIP Samples with Threaded Sleeve Stop & High G Trigger

Description	Qty.	Cal. MM	Zone	Tube	Temp. °F	Set (Sec.)	Chrono Time (Sec.)			Remarks
							n	$\overline{X}$	σ	
Group 1 PIP Units	10	105	8	XM204	70	75	9	74.795	.156	1 Dud, N.F.G.I. (Wet Ground)
Control Units	10	105	8	XM204	70	75	10	75.000	.127	
Group 2 PIP Units	10	155	Charge 119	M185	70	75	9	* 74.982	.194	Projectile 483 All functioned. 1 lost time.
Control Units	10	155	Charge 119	M185	70	75	10	* 75.099	.188	Projectile 483 All functioned.
Group 3 PIP Units	10	155	Charge 119	M185	70	75	10	74.841	.073	Projectile M107
Control Units	10	155	Charge 119	M185	70	75	9	75.084	.111	Projectile M107 1 outlier = 77.803

*Times taken with stop watch, use lamp black powder for spotting charge.

Net torque on timer = gage torque - timer preloaded torque

Through 5 to 1 ratio speed reduction, the net torque is increased by five times. At the timer-stop, the torque is

$$5 \times (\text{net torque}) = 5 \times (\text{gage torque} - \text{timer preloaded torque})$$

The moment arm at the timer-stop is 0.75 inch, thus

$$\text{timer stop holding force} = \frac{5 \times (\text{gage torque} - \text{timer preloaded torque})}{0.75}$$

Model test data are listed in Table 7.

Table 7 Model Test Data

S/N	Time Range sec.	Timer Setting Torque in-lb (preloaded)		Stop Holding Torque (gaged) in-lb		Stop Holding Force lb.	
		CCW	CW	Upper (1)	Lower (2)	Upper (1)	Lower (2)
1	206.4	8	8	23	30.5	100	over 147
2	206.5	7.5	7	23.5	36	106.6	over 193
3	206.5	7	6	24	38	113.3	over 213
4	206.3	6.5	65	No destructive test data			
5	206.5	6.5	7				

Notes:

(1) Test was not destructive. Applied torque to the upper stop by turning the setting shaft counterclockwise, and increased the value until the time setting began to creep. Holding torque was read from the gage and holding force was derived from the torque.

(2) Destructive test: Applied torque to the lower stop by turning the setting shaft clockwise, and increased the value until the mechanism broke. Obtained the gage torque at which failure occurred. Inspection of the failures found that the timer lower stop survived, but the dowel pins of the timer ring gear were sheared off. (Note that the destructive test can be performed on one stop only. Once the mechanism broke, no further test can be made on the same timer.)

Compare the test results to specification data:

Time setting range:	206 seconds
Timer preloaded torque:	5 to 8 in-lb.
Gripring clutch slip torque:	9 to 13 in-lb.

And the maximum tangential force that the timer-stop may encounter is 86.7 lb. Test samples have an average time setting of 206.4 seconds, and the torques required to set the timer ranging from 6 to 8 in-lb which fall within the specified limits. The timer-stops hold a minimum torque of 23 in-lb corresponding to a holding force of 100 lb. They are greater than the maximum slip torque of the grip-ring clutch and the maximum tangential force at stop pins respectively.

JOLT & JUMBLE TEST

The purpose of the Jolt and Jumble test is to check the safety and ruggedness of the fuze models with Threaded Sleeve Timer Stop and Modified Trigger Assembly. Nine (9) units were sampled, and tests were conducted per MIL-STD-331A, Test 101.2 Jolt and 102.1 Jumble. Tested samples had been inspected, the results were listed in Table 8 below:

Table 8. Jolt and Jumble Test Results

S/N	Explosive Element	Fuze Package	Timer Stop	Trigger Assy
1	Not initiated	No damages	Intact	Intact
2	Not initiated	No damages	Intact	Intact
3	Not initiated	No damages	Intact	Intact
4	Not initiated	No damages	Intact	Intact
5	Not initiated	No damages	Intact	Intact
6	Not initiated	No damages	Intact	Intact
7	Not initiated	No damages	Intact	Intact
8	Not initiated	No damages	Intact	Intact
9	Not initiated	No damages	Intact	Intact

There was no damage observed to be related to the modification of Product Improvement Program.

ECONOMIC EVALUATIONS

To obtain the cost savings of PIP modifications, an investigation was made on manufacturing cost of modified parts, based on in-house work studies and vendor's quotations, and the costs of modified parts were compared to that of corresponding current designs.

COSTS OF THREADED SLEEVE TIMER STOP

By replacing the tumbler stop with the threaded sleeve stop, eight parts are eliminated. They are:

(1) Internal Tab Tumbler	9236682
(1) Tumbler	9236683-1
(3) Tumbler	9236683-2
(2) Tumbler	9236684
(1) Sleeve Key	9236632

The new design introduces five new parts:

(1) Follower

(2) Stop pin

(1) Washer

(1) Spacer

and modifies three existing parts:

(1) Sleeve	9236631
(1) Main Spring Barrel	9236696
(1) Barrel Housing	9236688

The manufacturing costs' comparisons between parts of Threaded Sleeve Stop and those of Tumbler Stop are listed in Tables 9A, 9B and 9C, based on a production volume of 300, 000 units.

Item	BSIC Current Mfg. Proccess	Tumbler Sleeve With End Groove *	PIP Sleeve With Thread/End Groove*
Impact (Subcontract)	.410	.410	.410
Turning (Subcontract)		.450	.473
Turning (In-House Labor) Punch (5) Holes (In-House Labor)	.240	.030	.030
Auto Cycle (In-House Labor)		.014	.030
Over Head (107.4% Of Labor Cost)	.257	.047	.064
Total	.907	.951	1.007

*Sleeve with end groove is the proposed design for plastic P.D. Housing.

TABLE 9A. SLEEVE COST COMPARISON

TABLE 9B-PIP TIMER STOP UNIT COST SAVINGS

COMPARISON MADE WITH TUMBLER SYSTEM WITH
SLEEVE OF CURRENT BSIC MFG. PROCESS

Items	Tumbler	PIP Threaded-Sleeve	Savings *
(1) Sleeve	.9070 **	1.0070	- .1000
(1) Upper Stop Pin	-	.0713	- .0713
(1) Lower Stop Pin	-	.0713	- .0713
(1) Key, Sleeve	.0415	-	+ .0415
(1) Follower	-	.0584	- .0584
(1) Spacer	-	.0657	- .0657
(1) Washer	-	.0550	- .0550
(1) Barrel Housing	1.2230	1.2230	0
(1) TAB Tumbler	.0900	-	+ .0900
(1) Tumbler - 1	.0900	-	+ .0900
(3) Tumbler - 2	.2700	-	+ .2700
(2) Tumbler Keeper	.1368	-	+ .1368
Tumbler Assembly	.0621	-	+ .0621
Timer Assembly	.0075	.1000	- .0925
Total ***	2.8279	2.6517	+ .1762

* Positive sign for cost savings. Negative sign for cost increase.

** BSIC current manufacturing sleeve.

*** Total costs incude materials. Labor and overhead.

TABLE 9C-PIP TIMER STOP UNIT COST SAVINGS

COMPARISON MADE WITH TUMBLER SYSTEM WITH SLEEVE HAVING END GROOVE FOR PLASTIC P.D. HOUSING

Items	Tumbler	PIP Threaded Sleeve	Savings *
(1) Sleeve	.9510 **	1.0070	- .0560
(1) Upper Stop Pin	-	.0713	- .0713
(1) Lower Stop Pin	-	.0713	- .0713
(1) Key, Sleeve	.0415	-	+ .0415
(1) Follower	-	.0584	- .0584
(1) Spacer	-	.0657	- .0657
(1) Washer	-	.0550	- .0550
(1) Barrel Housing	1.2230	1.2230	0
(1) TAB Tumbler	.0900	-	+ .0900
(1) Tumbler - 1	.0900	-	+ .0900
(3) Tumbler - 2	.2700	-	+ .2700
(2) Tumbler Keeper	.1368	-	+ .1368
Tumbler Assembly	.0621	-	+ .0621
Timer Assembly	.0075	.1000	- .0925
Total ***	2.8719	2.6517	+ .2202

* Positive sign for cost savings. Negative sign for cost increase.

** Modified sleeve having end groove for plastic P.D. housing,

*** Total costs include materials. Labor and overhead.

COSTS OF MODIFIED TRIGGER ASSEMBLY

Modification is made on the trigger spacer die-cast only. An estimation on the die-cast, based on 200,000 production, obtains the unit cost of $.380 plus tooling. Comparing to the current trigger spacer die-cast bought at an average unit price of $.354, the new design costs $.026 higher. This increase of cost is the compensation for the reliable fuze function at 30,000 g's level.

COST OF COMBINATIONS OF THREADED SLEEVE STOP AND MODIFIED TRIGGER ASSEMBLY

Table 10. Manufacturing Cost per Unit

	Current Design Std. Parts	Standard Design with end-grooved Sleeve	PIP Modif. Sleeve with end groove and thread
Timer Stop	2.8279	2.8719	2.6517
Trigger Spacer Die-cast	.3540	.3540	.3800
Combined	3.1819	3.2259	3.0317

Comparing with current design of all standard parts, PIP modification has a manufacturing cost saving of

$3.1819 - $3.0317 = $0.1502 per unit

Comparing with standard design with end-grooved sleeve, the PIP modification saving is

$3.2259 - $3.0317 = $0.1942

TASK 2. INCREASE TORQUE AVAILABLE TO THE TIMER TO REDUCE PRODUCTION LINE FALLOUT

Two engineering approaches were proposed for this task.

INVESTIGATION OF GEAR TRAIN EFFICIENCIES

A computer program was prepared by ARRADCOM, and operation was performed by BSIC to analyse possible parameters that affect the point efficiency and cycle efficiency of meshing gears during torque transmission. Mathematical analysis had been made on gear configurations, pivots, spin rates and variation of friction coefficient etc. complete data were exhibited in a computer study report which was released with the progress report of August 1981. A data summary is exhibited in Appendix B of this report. Following are high-lights of the summary:

1) Change of mass of gears had no significant effect on cycle and point efficiencies.

2) Change of pivot radii did not affect efficiencies noticeably.

3) Change of distance from spin axis to various pivot axes was not significant.

4) Changing spin rate from 7,500 RPM to 30,000 RPM. Cycle efficiency was changed by 6%,decreased.

5) Changing parameter "PSUBD1" & "PSUBD2" (diametral pitch). "CAPRP1" & CAPRP2" (pitch radii) changed cycle efficiencies.

6) Friction coefficient of gear contact surfaces affected cycle efficencies noticeably.

From the above results, the most substantial way of increasing torque transmission efficiency is changing the friction coefficient of gear surfaces. The computer analysis indicates that cycle efficiency of .98 can be acquired by bringing down the friction coefficient of gear surface to .05.

PROPOSED DESIGN MODIFICATION

Coefficient of surface friction is dependent on material and surface treatment. A dry lubricant called EMRALON was introduced for gear train surface treatment. This process was proceeded by coating a dry lubricant film of EMRALON on escape wheel and pinion assembly, gear and pinion No. 1 assembly, gear and pinion No. 2 assembly and ring gear. Samples had been obtained for a proving test which consisted a running torque test and a spin test, and the observation of chemical compatibility between EMRALON and other fuze parts lubricants.

TEST AND EVALUATION OF EMRALON TREATED GEAR TRAIN

a) Running torque test: This test was conducted on five timers with EMRALON treated gear train and five regular timers as control group. The test was performed by using dead weight to provide necessary torque to run the timers. Minimum running torque for each timer was recorded. Data are exhibited in Table 11.

Table 11. Running Torque Comparison

	Minimum Running Torque (in-oz)					
Serial No.	1	2	3	4	5	$\bar{X}$
EMRALON unit	3.5	4.0	6.0	4.0	4.0	4.3
Control unit	2.5	3.5	5.5	3.0	4.0	3.7

Above data does not show improvement of torque on units with EMRALON treated gear train.

b) Spin Test: Tests were conducted at incremental spin rate up to 24K rpm. Beat rates were recorded at 15K rpm, 22K rpm and 24K rpm. Test samples included in two test groups. Sample status are described below:

Group I: timer with EMRALON treated gear train, pretested without applying lubricating oil, second test after applying lubricating oil to pallet pins only.

Group II: timer with EMRALON treated gear train, regularly applied lubricating oil to all required spots.

Group III: regular units as control group.

TABLE 12. ABSTRACTED SPIN TEST RESULTS

	Beat Rate at 15K rpm		Predicted 75 sec. Time	
	$\overline{X}$	σ	$\overline{X}$	σ
Group I	80.65	.108	75.083	.100
Group II	80.64	.240	75.000	.122
Control	80.63	.065	75.104	.061

Standard deviations on 15K rpm beat rate and predicted 75 second time were larger for timers with EMRALON treated gear train. The result also showed a comparatively abrupt change of beat rate for EMRALON timers when spin rate was increased from 15K rpm to 22K rpm. Complete data were listed in Appendix C.

c) Chemical compatibility: observation was made on EMRALON treated parts lubricated with Astro oil, after one week storage period. No trace of Chemical reaction were found under 20x magnification.

COMMENT

Running torque test indicated that the EMRALON treated gear train had no improvement in torque transmission, and spin test showed a declining performance for EMRALON timers. Further test for EMRALON treatment is not recommended.

IMPROVING MAINSPRING TORQUE

DESIGN MODIFICATION

A conference held by personnel of ARRADCOM, BSIC and Sandvick Inc. (Spring manufacturer) reviewed spring background, design parameters and test consideration and proposed a spring test program toevaluate three types of spring modification:

a. VYDAX surface treatment
b. Bridled mainspring
c. Combination of VYDAX and Bridle.

VYDAX mainspring is a process of surface treatment with a coating of low friction coefficient material per MIL-L-60326, to reduce coil friction. It is a low cost process, without changing the form of the spring. Bridled main spring has more advance modification, to be described in 4.2.2.

DESCRIPTION OF BRIDLED MAINSPRING

"Bridle" is a metal tab of same material as the mainspring, 2 inches long, spot welded to the end of outer coil of the mainspring as shown in Figures 8 and 9. The function of the bridle is to keep uniform spacing and concentricity of coil while the spring is being unwound from fully wound.

Figures 10, 11, 12 and 13 illustrate configurations of coil of mainspring wound up to 7 1/2 turns, then unwound to 6 1/2 turns, 5 1/2 turns and 3 1/2 turns for comparison of bridled mainspring and regular springs. Significant differences between bridled and regular springs are observed, especially at 3 1/2 turns, where the coil's spacing is much more uniform and the coils are much more concentric to the center for bridled mainspring than regular mainspring.

MAINSPRING EVALUATION

A test program has been conducted to evaluate two modified spring configurations: 1) Spring with VYDAX coating and 2) Spring with both VYDAX coating and Bridle. The test program consisted of an output torque evaluation and a performance evaluation.

Output torque evaluation The situation of spring coil spacing and concentricity affects the quantity and quality of spring output torque. Measurement has been made on output torque of ten mainsprings with Bridle, and ten mainsprings without Bridle, wound up at 7 3/4 turns, 6 3/4 turns, 5 3/4 turns and 4 3/4 turns. The results are listed in Table 12. Improvement of output torque is observed for "Bridled" mainspring. It is significant at fewer spring turns. The quality of output torque is illustrated in the hysteresis curves Figure 14, 15 and 16. These curves were made for one spring torque cycle, from free spring to fully wound and then unwound, on regular mainspring, spring with VYDAX coating and spring with both VYDAX coating and Bridle. The regular spring torque curve shows hysteresis and erratic on unwinding. This indicates the largest loss and unstable output torque. The VYDAX spring torque curve shows low hysteresis but still erratic torque on unwinding. The spring with both VYDAX and Bridle has a torque curve of low hysteresis and very smooth form on unwinding. This indicates that this spring configuration has higher torque efficiency and a more stable output than current spring.

Evaluation of mainspring performance This program included a laboratory test and a ballistic test. The laboratory test consisted of a systematic test of two test sample groups and a control group. Test groups are springs with VYDAX coating and springs with both VYDAX coating and Bridle. Each group contained thirty units divided into three lots, ten units a lot, to be spin-tested at 150 second concentric assembly, at 150 seconds with .030 eccentric assembly and at 175 second with .030 eccentric assembly respectively. Beat rates of each test sample were plotted at spin rates of 15,000 RPM and 22,000 RPM. The complete test data are exhibited in Appendix D. Following is the summary of the spin test:
Over the entire running time, no spring type showed a clear cut advantage. However, during the last fifty seconds of running time when the mainspring torque was lower, the VYDAX and Bridled spring timers showed considerably better performance in concentric spin; In eccentric spin, all springs were comparable at low speed, but at high speed, the Bridled spring was clearly superior.

The ballistic test was conducted on fuzes with bridled spring. Standard fuzes were used as control units. Five test groups and five control groups were sampled for testing in various conditions. Test plan and summarized test results are illustrated in Table 13. The test results show that the modification of mainspring passes the proving test.

COMPARISON OF MAINSPRING COSTS

According to a vendor's quotation, based on a lot of 100,000 units, the costs for regular mainspring and bridled mainspring are as following:

Regular Mainspring	$0.8014 per unit
Bridled Mainspring	$1.375 per unit

The bridled mainspring costs about 70% higher than regular mainspring.

BRIDLED MAINSPRING COST JUSTIFICATION

The bridled mainspring has higher torque efficiency and more stable output than regular mainspring. It appeared superior characteristics at the 100 to 200 seconds range of timer operation and at higher spin rate. This performance might be valuable in future weapon systems with longer time of flight. However, the bridled mainspring incurs 70% higher cost than regulr mainspring, which can not be justified at this time.

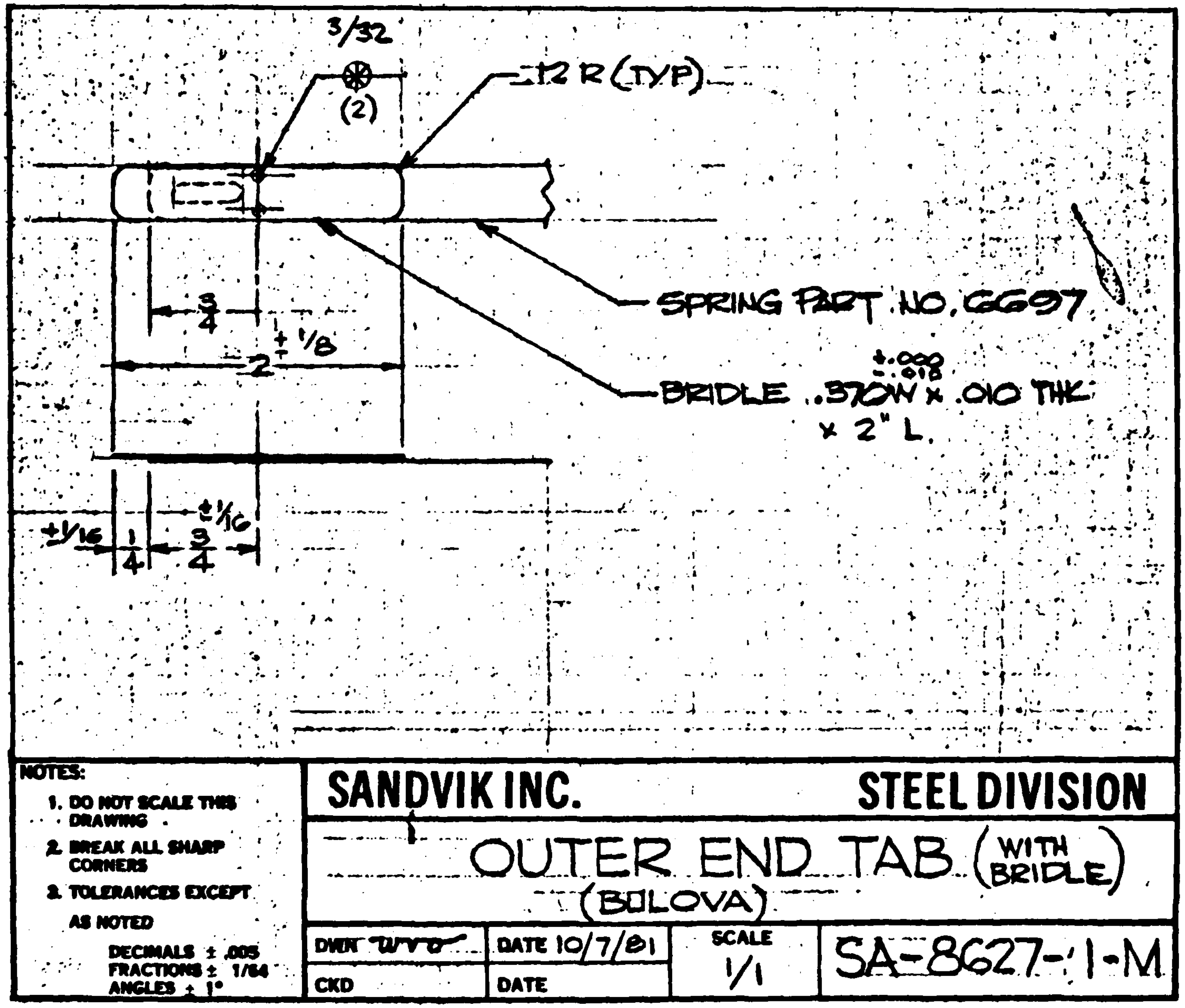


FIGURE 8. OUTER END TAB (WITH BRIDLE)

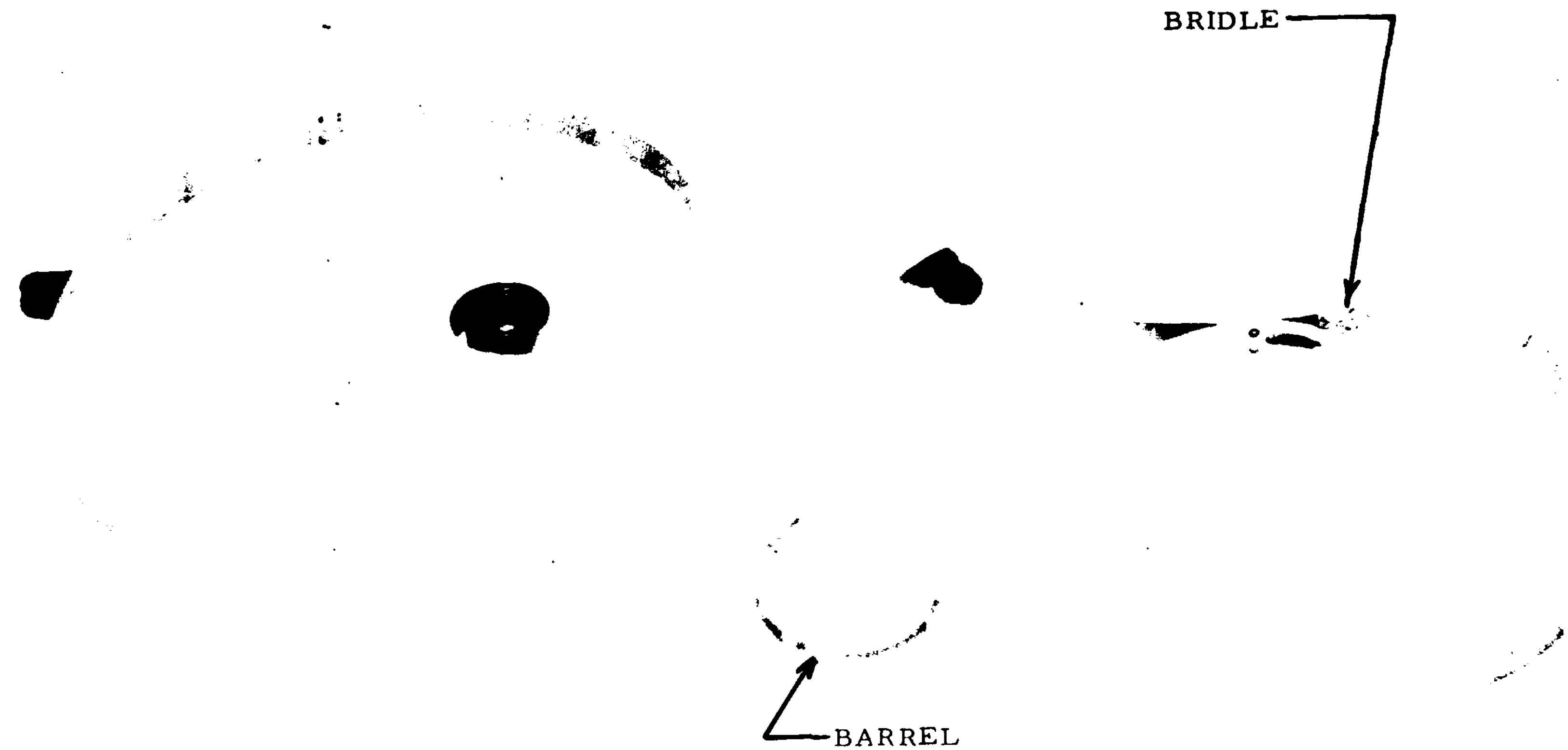
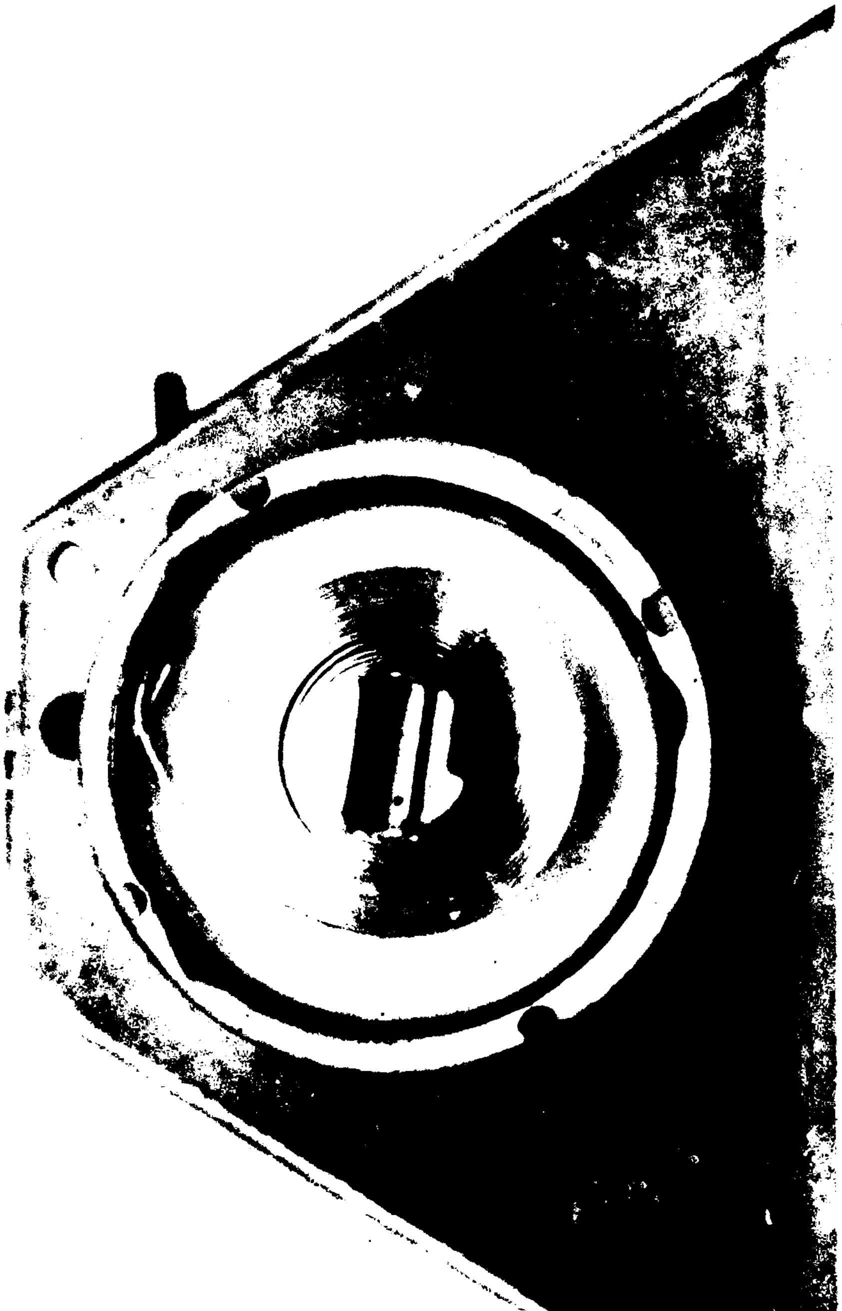


FIGURE 9. BRIDLED MAINSPRING

FIGURE 10a. BRIDLED SPRING 7 1/2 TURNS



STD 7½

FIGURE 10b. REGULAR SPRING 7 1/2 TURNS

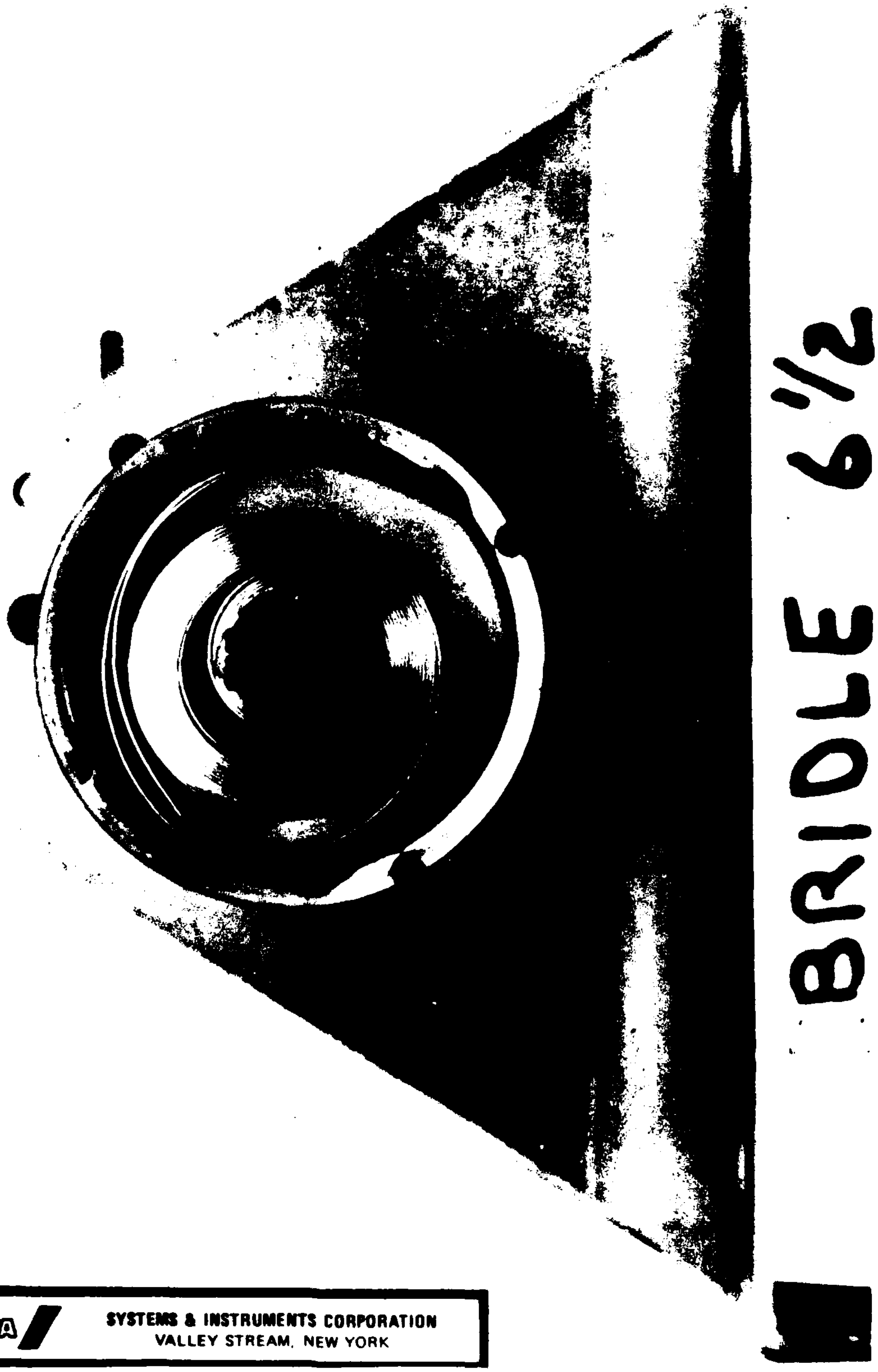


FIGURE 11a. BRIDLED SPRING 6 1/2 TURNS

BULOVA SYSTEMS & INSTRUMENTS CORPORATION
VALLEY STREAM, NEW YORK

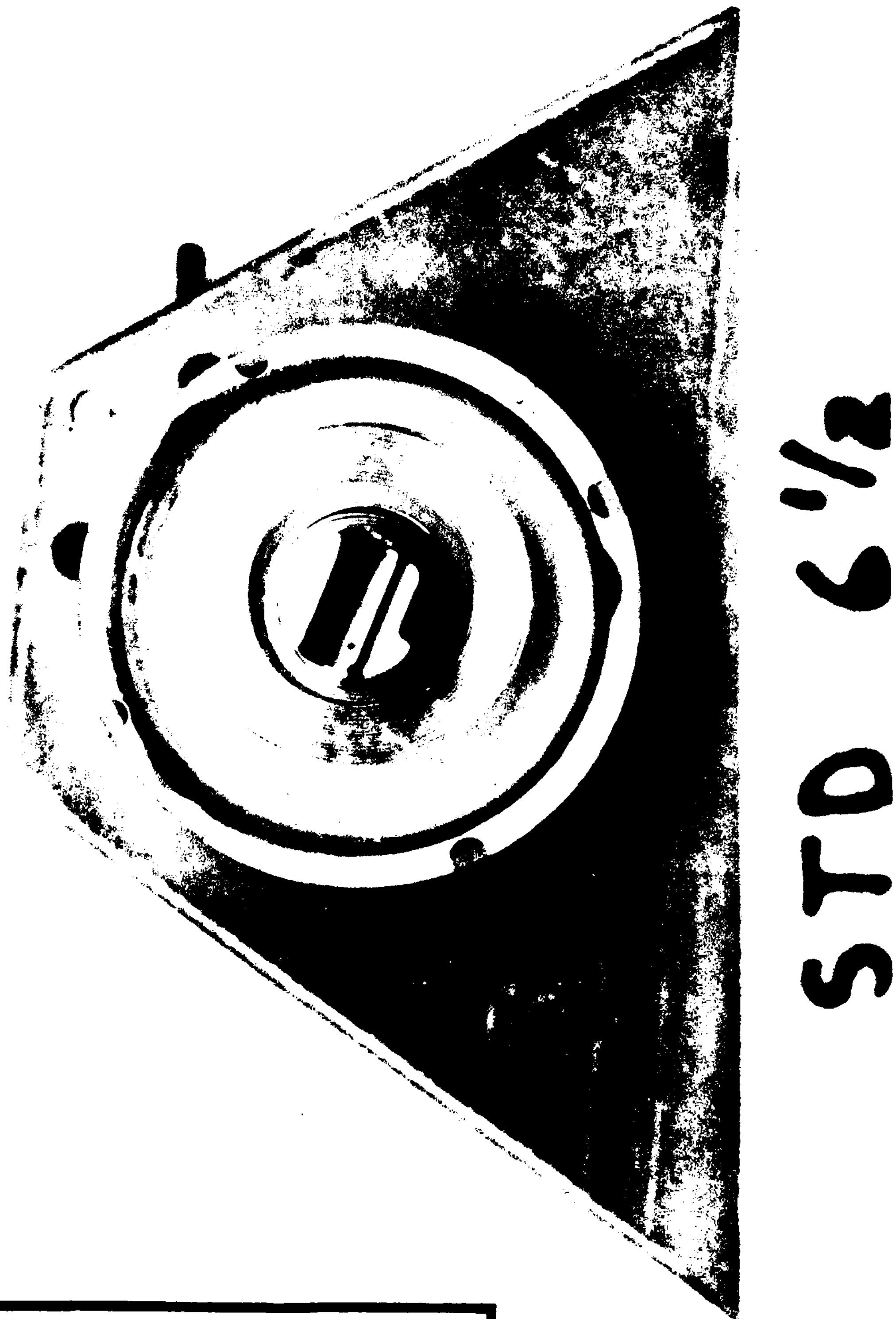


FIGURE 11b. REGULAR SPRING 6 1/2 TURNS

FIGURE 12a. BRIDLED SPRING 5 1/2 TURNS

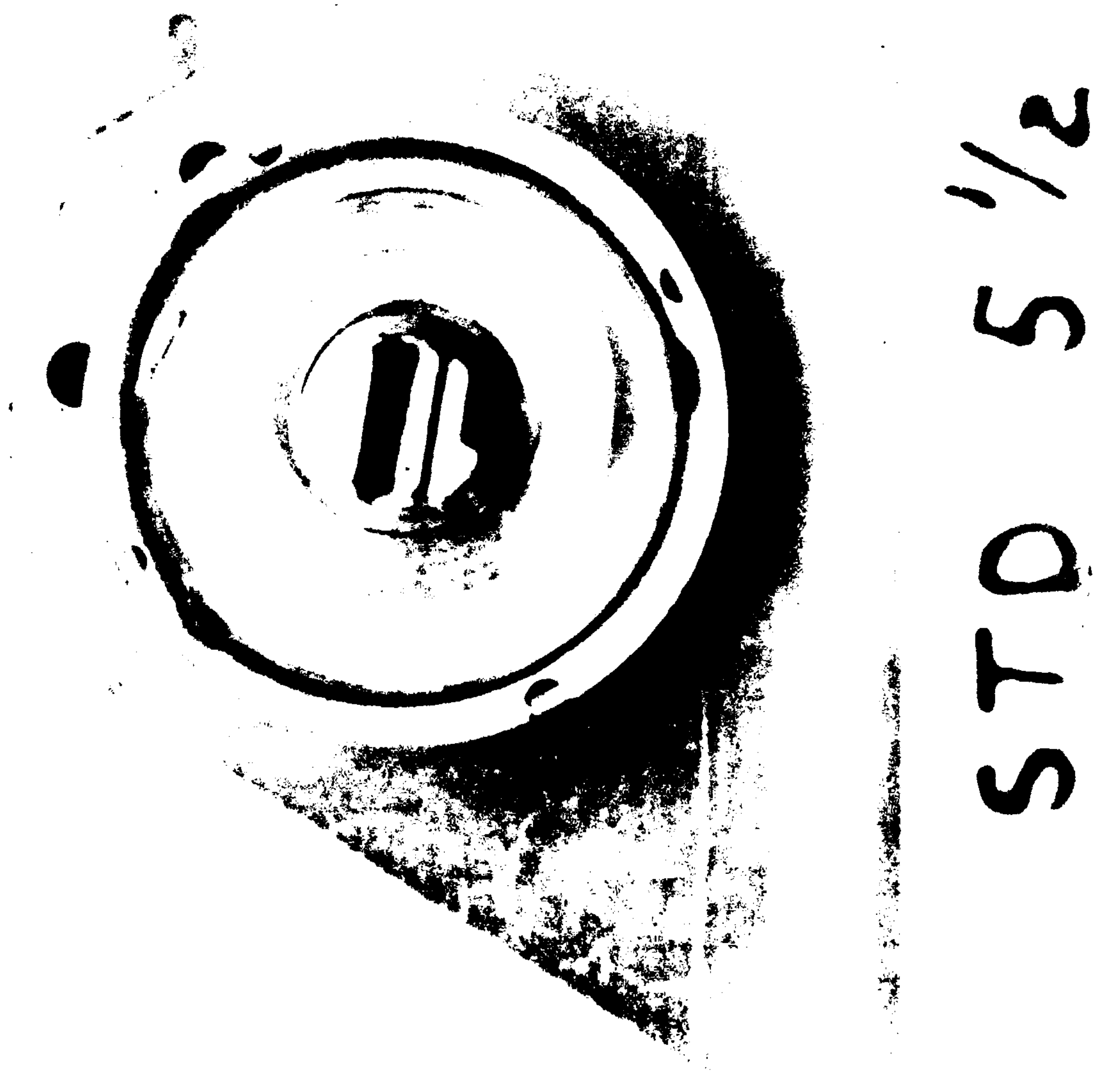


FIGURE 12b. REGULAR SPRING 5 1/2 TURNS

FIGURE 13a. BRIDLED SPRING 3 1/2 TURNS

BRIDLE

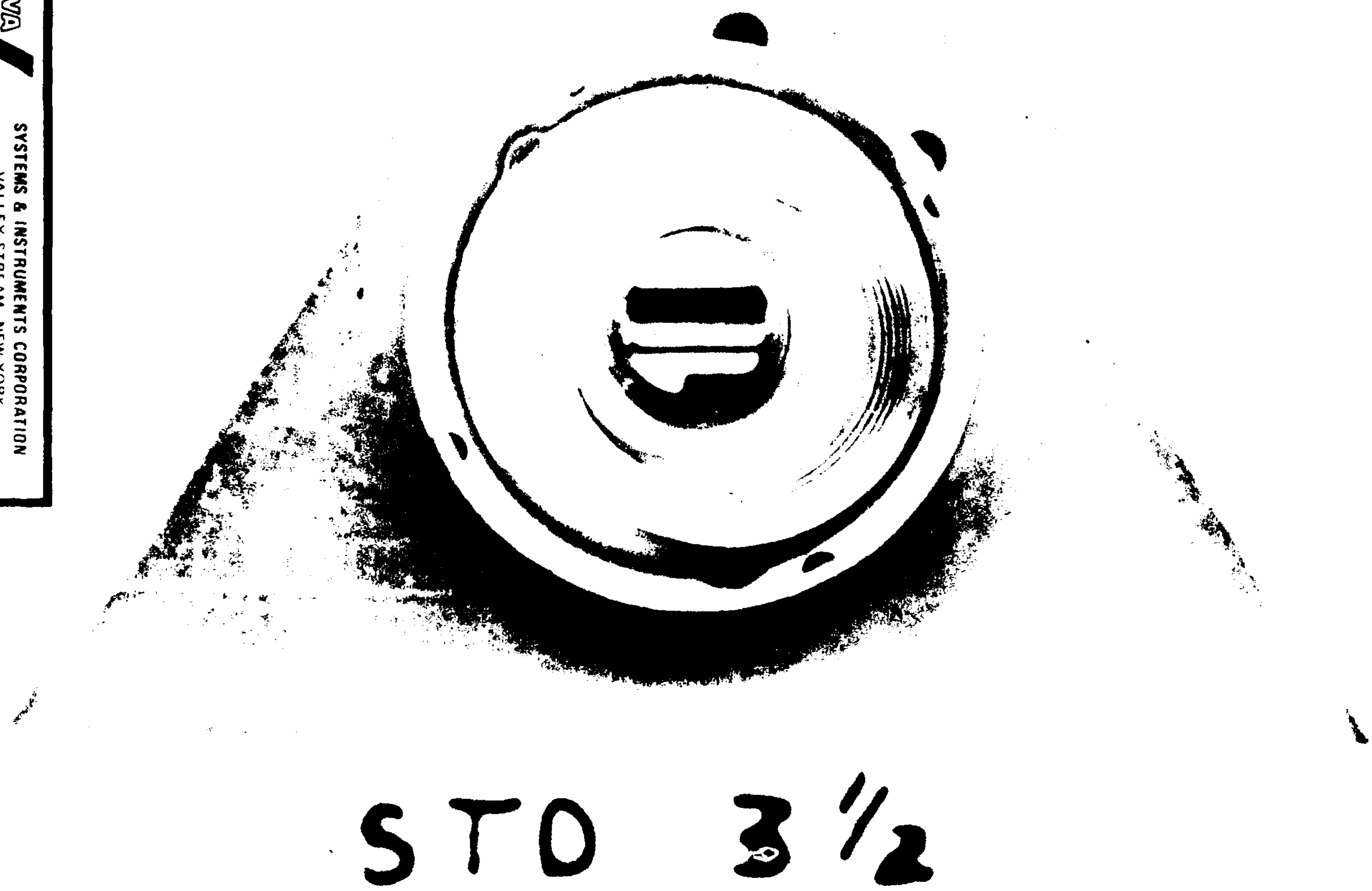


FIGURE 13b. REGULAR SPRING 3 1/2 TURNS

TABLE 13. SPRING OUTPUT TORQUE TEST

SPRING TYPE	S/N	OUTPUT TORQUE (IN-OZ) AT TURNS OF 7 3/4	6 3/4	5 3/4	4 3/4
I. VYDAX ONLY	1	31	29	28	26
	2	31	29	27.5	25.5
	3	32	30.5	28.5	26.5
	4	31	29	27	25
	5	31	30	28.5	27
	6	32	30	28	26
	7	30.5	29	28	26
	8	32	29	27	25
	9	31.5	30	28	26.5
	10	32	29.5	28	26
	$\overline{X}$	31.4	29.5	27.9	26
	σ	.568	.577	.530	.643
II. BRIDLE AND VYDAX	1	32.5	31	29.5	28
	2	32.5	31	29.5	28
	3	33	31	29.5	28
	4	32.5	31	29.5	28
	5	34	31.5	30	28.5
	6	33.5	31.5	30	28
	7	32	31	29.5	28
	8	32.5	31	30	28
	9	32	31	29.5	28
	10	32.5	31	29.5	28
	$\overline{X}$	32.7	31.1	29.7	28.1
	σ	.632	.211	.242	.158

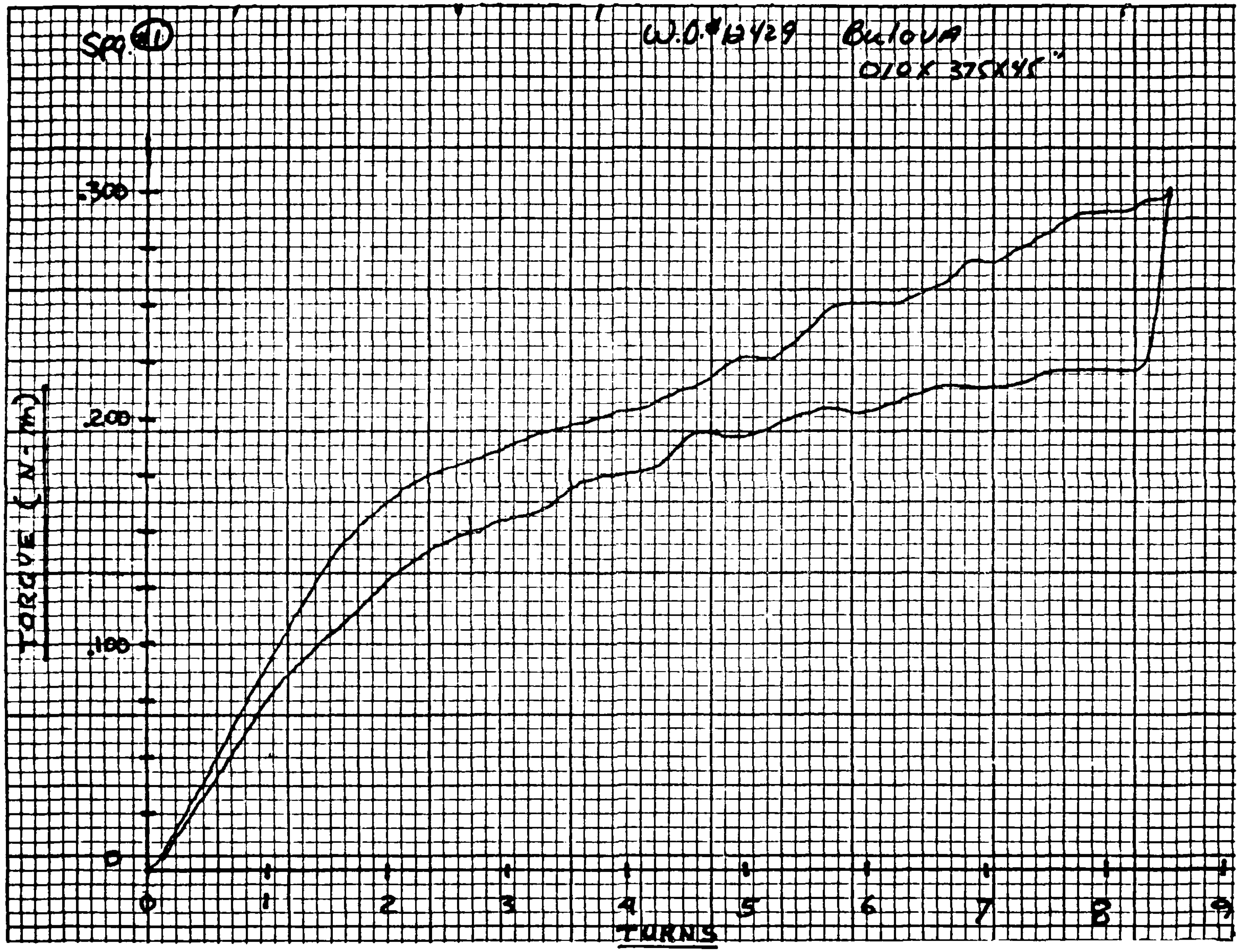


FIGURE 14. REGULAR PRODUCTION SPRING. NO VYDAX OR BRIDLE (Temper B)

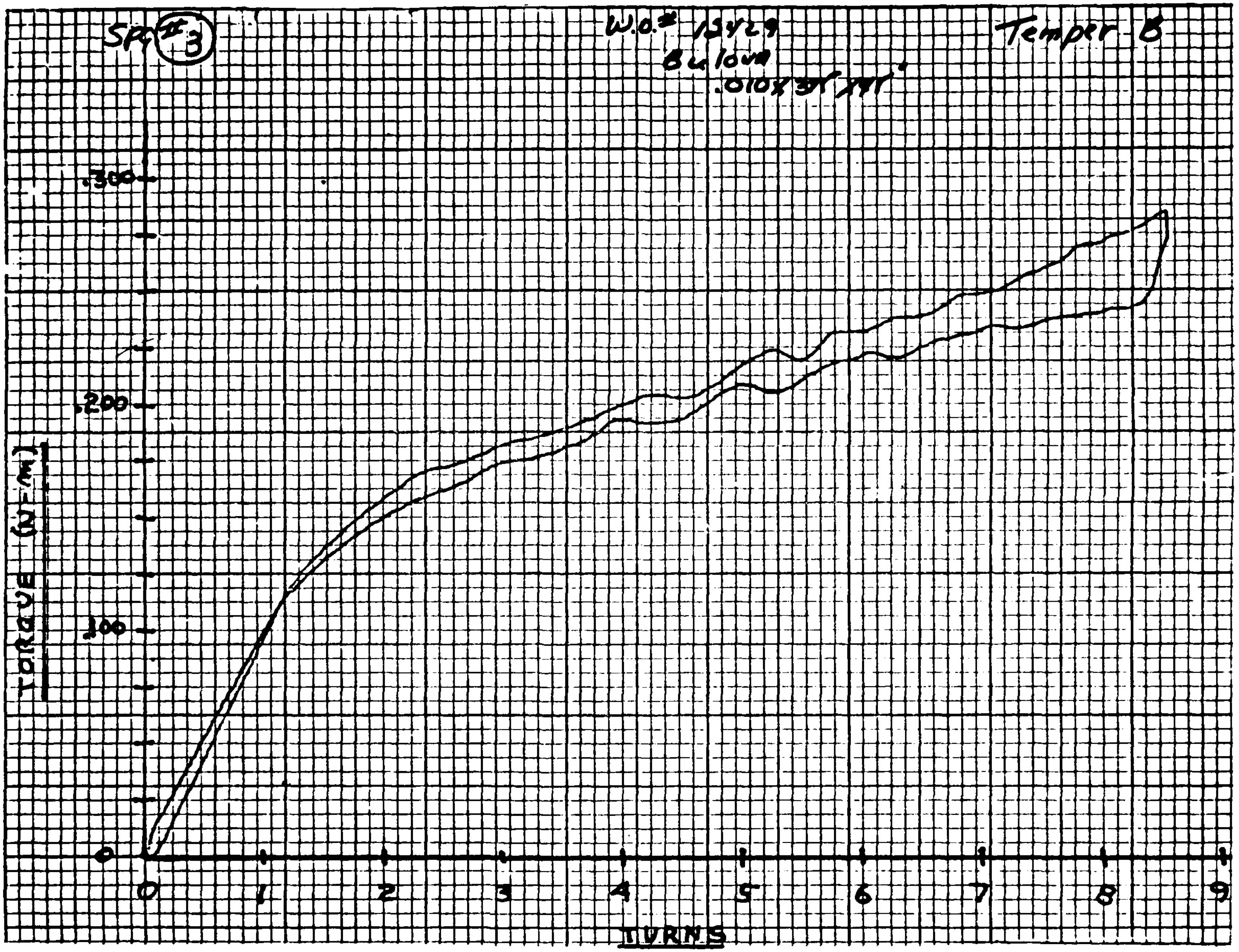


FIGURE 15. SPRING WITH VYDAX--NO BRIDLE

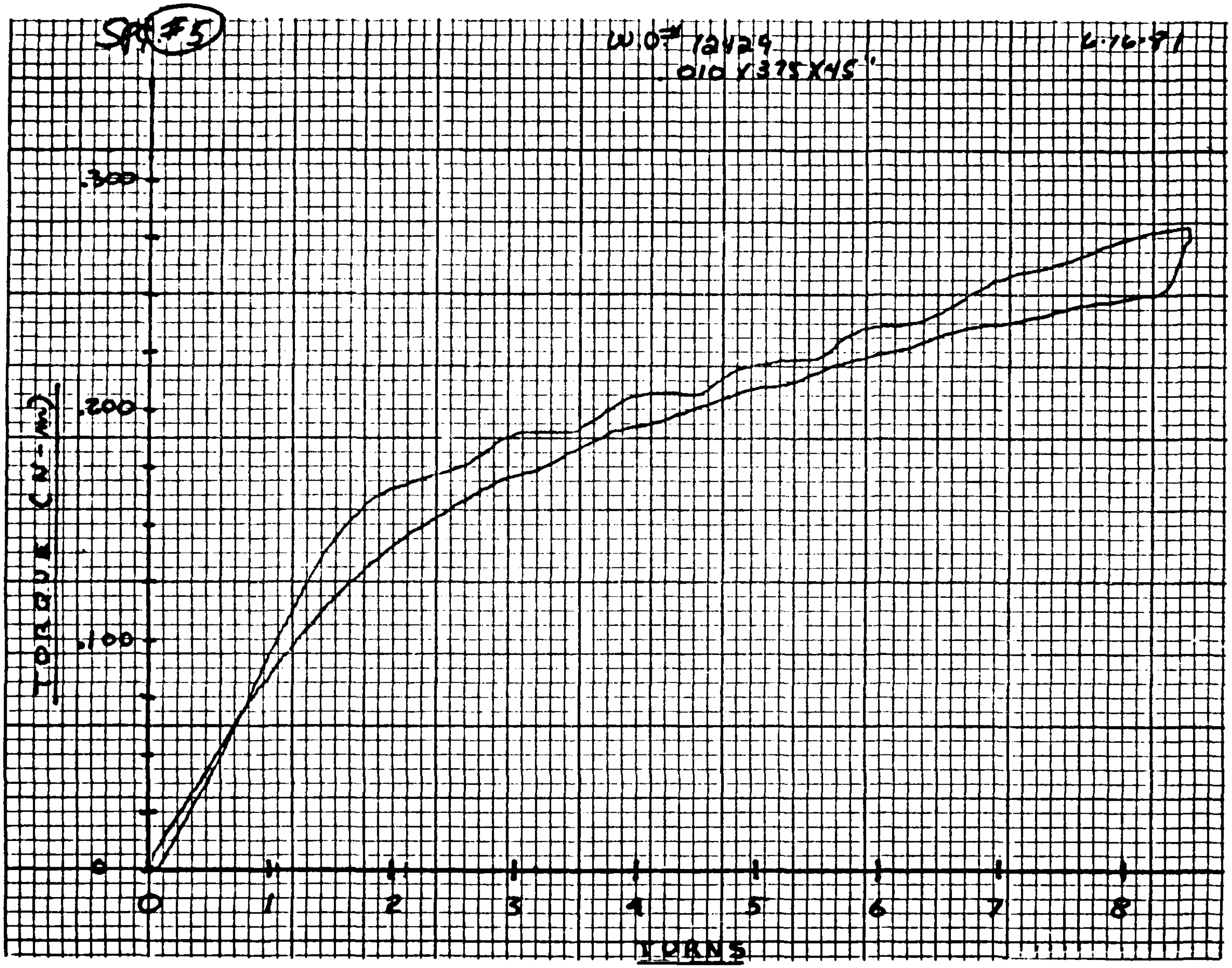


Figure 16. Spring With VYDAX and 2-inch Bridle Spotwelded to Spring (Temper B)

TABLE 14. BALLISTIC TEST SUMMARY

TPR 2594 Supplement 29
Date of Test: June 30, 1982

M577 PIP Samples with BRIDLED Mainspring

Description	Qty	Cal. MM	Zone	Tube	Temp °F	Set (Sec.)	Chrono Time (Sec.) $\bar{X}$	σ	n	Remarks
PIP Units # 1-10	10	155	8	M198	70	100	100.056	.251	10	Hi-g Trigger 16,000 g , 16,000 rpm
Control Units # 51-60	10	155	8	M198	70	100	99.951	.295	9	16,000 g , 16,000 rpm 1 Dud FGI
PIP Units # 11-20	10	105	8	M204	70	75	74.912	.162	8	Hi-g Trigger, 21,000 g 22,000 rpm 1 Dud FGI 1 outlier = 75.732
Control Units # 61-70	10	105	8	M204	70	75	75.088	.145	10	21,000 g . 22,000 rpm
PIP Units # 21-30	10	105	7	M103	70	50	50.060	.069	10	Std. Trigger
Control Units # 71-80	10	105	7	M103	70	50	50.036	.076	9	1 lost time
PIP Units # 31-40	10	155	8	M185	70	75	75.043	.096	8	Std. Trigger 1 Dud NFGI 1 Outlier = 76.975
Control Units # 81-90	10	155	8	M185	70	75	75.016	.266	10	
PIP Units # 41-50	10	155	8	M185	70	50	49.995	.040	10	Std. Trigger
Control Units # 91-100	10	155	8	M185	70	50	50.012	.063	10	

CONCLUSIONS AND RECOMMENDATIONS

The combination design of threaded sleeve timer stop and modified trigger assembly has an estimated unit cost saving of $0.194 with improvement of fuze reliability at 30,000 g level. It is recommended for use in the M577 MTSQ Fuze.

Emralon lubrication does not improve timer performance. No further efforts is recommended for reducing friction coefficient of gear surfaces.

Bridled mainspring incurs 70% higher cost than regular mainspring. Although the design appears to have superior characteristics, the high cost cannot be justified at this time.

APPENDIX A

STOP TEST

M577 PIP THREADED-SLEEVE TIMER STOP

STOP PIN STRENGTH TEST

Date of Test: August 6, 1982.

Object: The object of the test program was to evaluate the strength of timer stops for the setting torque to be held.

Configuration: The configuration consisted of one M577 fuze assembly with a threaded-sleeve timer stop replacing the tumbler stop. Stop pins were then pressed fit into predrilled pin holes in the threaded-sleeve without staking.

Procedure: For the slip test, torque was applied to stop pins by turning the setting key engaging with grip-ring slip clutch at lower and upper stops, respectively, until the grip-ring clutch slipped. The fuze was then disassembled and the stop pins, sleeve and follower were inspected.

For the destructive test, the old follower was replaced and the fuze was reassembled with the setting key pinned to the setting shaft, which disabled the grip-ring clutch. Torque was applied as much as possible to break the stops. The fuze was then disassembled and its parts were inspected.

Test Results:

For the slip test, torque was increased to lower stop pin to 16 in-lb when the grip-ring clutch slipped. When torque was applied to the upper stop pin and the value was increased to 13 in-lb., the grip-ring clutch slipped again. Inspection of parts indicated that the stop pins had no trace of change both in part shape and seating condition; however, the follower had worn edges at both ends of the tooth where the stop pins hit.

2. Destructive Test: - Applied torque to the lower stop pin and increased the value to 28 in-lb (note that the slip clutch was disabled), the stop functioned. However, the timer setting crept 0.3 second from 93.8 to 93.5. Applied torque to the upper stop pin and increased the value to 24 in-lb, the stop held, but the timer setting shifted 0.4 second from 200.0 to 200.4. Inspection of parts revealed that the stop pins were in good shape and seating properly. The sleeve threads were intact. The follower tooth was deformed in both ends, .030" cut on the upper stop side and .020" cut on the lower stop side (total tooth width .155" approximately).

Comments: -

1. The stop pins held the torques of 24 in-lb and 28 in-lb for 200 seconds setting and shipping setting respectively. The factors of safety were 1.6 and 1.9, corresponding to a maximum setting torque of 15 in-lb specified.

2. The scroll track has clearances of 4.8° to 7.8° (0.67 seconds to 1.08 seconds) on the shipping setting side, and 52° to 55° (7.22 seconds to 7.64 seconds) on the 200 seconds setting side. The timer stops held within this limit when destructive torques were applied.

APPENDIX B

POINT AND CYCLE EFFICIENCIES OF THE GEAR TRAINS

Introduction

This report describes the results of an analytical study of the point and cycle efficiencies of various types of fuze gear trains. Comparisons are presented between involute and clock tooth profiles for two and three pass step-up gear meshes which operate in spin and non-spin environments. In sights are provided concerning the reasons for differences in efficiencies of these gear trains. The analyses on which these results are based are given in detail in the report.

To this end, computer models of such gear trains, with both involute and clock (ogival) tooth shapes have been developed. These programs allow the determination of point and cycle efficiencies for these gear trains. All models allow a wide variety of parameter variations.

Program Invol 1: Design of an involute gear and pinion set with unity contact ratio.

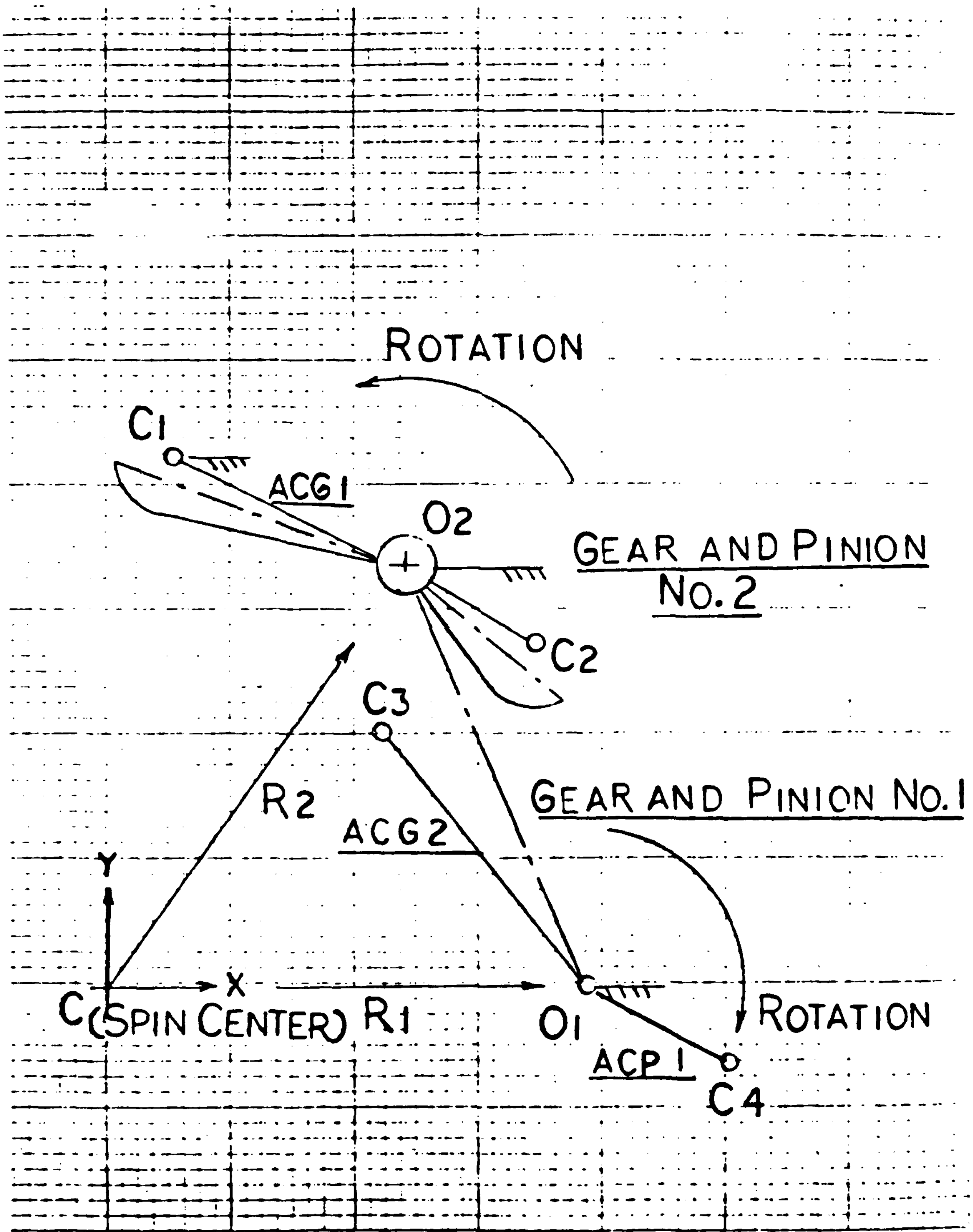
Program Invol 2: Point and cycle efficiencies for single pass involute step-up gear mesh with unity contact ratio.

Program Invol 3: Point and cycle efficiencies for three pass involute step-up gear train in spin environment.

Program Invol 4: Point and cycle efficiencies for two pass involute step-up gear train in spin environment.

Program Clock 1, Clock 2, and Clock 3 are not discussed.

Program Clock 4: point and cycle efficiencies for two pass clock (ogival) step-up gear train in spin environment.


ROTATION
C1
ACG1
O2
GEAR AND PINION
NO. 2
C2
C3
R2
ACG2
GEAR AND PINION NO. 1
Y
X
C (SPIN CENTER)
R1
O1
ROTATION
ACP 1
C4

Point and cycle efficiencies of the ogival and involute tooth forms used in mechanical escapement systems

By running programs Invol 4 and Clock 4 we are able to conclude which parameters of the gear train are more and which are less significant for the good point and cycle efficiencies. For instance:

A) Parameters which are not significant

a) The change of mass of the grears in reasonable limits is not significant. The cycle and point efficiencies are almost constant.

Invol 4:

M_1	M_2	Cycle Eff
$.1 \times 10^{-5}$ LB	$.09 \times 10^{-5}$ LB	.635
$.08 \times 10^{-5}$ LB	$.07 \times 10^{-5}$ LB	.636
$.06 \times 10^{-5}$ LB	$.05 \times 10^{-5}$ LB	.637

M_1 = Mass of Gear No. 1

M_2 = Mass of Gear No. 2

All other input parameters are constant

Clock 4 (Ogival Gearing in Spin Environment)

Input parameters:

Mesh 1: Gear No. 2 & Pinion No. 1

CAPRP 1 = pitch radius of gear = .1905 IN

RP 2 = " " " pinion= .0416 IN

ACG1 = distance from the center of rotation to the center of curvature = .1905 IN

ACP1 = .0416 IN (SEE FIGURE 1)

RHOG1 = radius of curvature = .021 IN

RHOP1 = .0069 IN

TG1 = max thickness = .0161 IN

TP1 = .0138 IN

NG1 = number of teeth = 37

NP2 = 8

Mesh 2: Gear No. 1 & Escape Pinion

CAPRP2 = .1595 IN
RP3 = .0416 IN
ACG2 = .1595 IN
ACP2 = .0416 IN
RHOG2 = .021 IN
RHOP2 = .0069 IN
TG2 = .0161 IN
TP2 = .0138 IN
NG2 = 31
NP3 = 8

In Addition

MU = .2
RPM = 10,000 RPM
M_1 = $.0121 \times 10^{-4}$ LB - SEC^2/IN
M_2 = $.0111 \times 10^{-4}$ "
M_3 = $.0017 \times 10^{-4}$ "
R_1 = .30330) Distances from the spin
R_2 = .20330) axis to the various
R_3 = 0) pivot axes.
RH01 = pivot radius = .0125 IN
RH02 = .0078 IN
RH03 = .0075 IN
MD = 0 = mass - distance product
K = 25 = Range divisor

M_1	M_2	Cycle Eff.
$.1 \times 10^{-5}$ LB	$.09 \times 10^{-5}$ LB	.726
$.08 \times 10^{-5}$ LB	$.07 \times 10^{-5}$ LB	.728
$.06 \times 10^{-5}$ LB	$.05 \times 10^{-5}$ LB	.729

ALL OTHER PARAMETERS ARE CONSTANT.

The facts given above allow the use of different materials

b) <u>The change of pivot radii</u> of the gears is not significant. (In reasonable limits)

CLOCK 4:

RH01	RH02	RH03	Cycle eff.
.013	.008	.008	.725
.011	.008	.008	.727
.010	.008	.008	.728
.009	.008	.008	.729
.008	.008	.008	.730
.007	.008	.008	.731
.013	.008	.006	.733
.013	.008	.005	.739
.013	.006	.008	.739
.013	.005	.008	.746

ALL OTHER INPUT PARAMETERS ARE CONSTANT

The facts above allow the use of not too small pivot diameters.

c) The change of distances from the spin axis to the various pivot AXES is not significant. (In reasonable limits)

INVOL 4:

R_1	R_2	Cycle eff.
.3033 IN	.2033 IN	.634
.4 IN	.3 IN	.632
.5 IN	.4 IN	.632

Clock 4:

R_1	R_2	Cycle eff
.3033 IN	.2033 IN	.722
.4 IN	.3 IN	.723
.5 IN	.4 IN	.722

d) By running program Invol 2 it was shown that influence of RB (base circle radius of pinion) is in the ratio 2/5 less significant than influence of CAPRB (base circle radius of gear). (For CAPRB was taken .3458 and for RB was taken .0522.)

B) Parameters which are significant

a) By changing spin rate from 7,500 RPM to 30,000 RPM, the cycle efficiency was changed for 6%.

Invol 4:

RPM	M_1	M_2	R_1	R_2	
7,500	$.121 \times 10^{-5}$ LB	$.111 \times 10^{-5}$ LB	.3033 IN	.2033 IN	.637
10,000	"	"	"	"	.634
12,500	"	"	"	"	.629
15,000	"	"	"	"	.624
20,000	"	"	"	"	.612
30,000	"	"	"	"	.576

Clock 4:

RPM	M_1	M_2	R_1	R_2	
7,500	$.121 \times 10^{-5}$ LB	$.111 \times 10^{-5}$ LB	.3033 IN	.2033 IN	.728
10,000	"	"	"	"	.725
12,500	"	"	"	"	.720
15,000	"	"	"	"	.715
20,000	"	"	"	"	.701
30,000	"	"	"	"	.661

b) By changing parameters "PSUBD1", "PSUBD2" (DIA PITCH), "CAPRP1", "CAPRP2" (PITCH RADII), WE ARE ABLE to improve cycle efficiency as shown below:

Clock 4:

PSUBD1	PSUBD2	CAPRP1	CAPRP2	Cycle eff.
101	101	.18317	.15347	.746
99	99	.18687	.15657	.756
97	97	.19072	.15979	.723
95	95	.19474	.16316	.703
93	93	.19892	.16667	.693
91	91	.20330	.17033	.685

PRESENT INPUT PARAMETERS

1. PSUBD1 = 97 ; PSUBD2 = 97
2. MIN = .372800 ; MU = .200 ; RPM = 10,000
3. CAPRP1= .19050 ; CAPRP2 = .15950
4. RP2 =.04160 ; RP3 = .04160
5. ACG1 = .19050 ; ACG2 = .15950; ACP1 = .04160; ACP2 = .0416
6. NG1 = 37 ; NG 2 = 31, NP2 = 8; NP3 =8
7. R1 = .30330 ; R2 = .20330; R3 = .00000
8. RH0G1 = .02100 ; RH0G2 = .02100; RHOP1 = .00690: RHOP2 = .00690
9. TG1 = .01610 ; TG2 = .01610, TPI =.01380; TP2=.01380
10. M1 = .12100E-05 ; M2 = .11100E-05; M3 = .17000 E-06
11. RH01 =.013; RH02=.008; RH03=.008
12. MD =0; K=25.0; PHD0T1 = 1.0; J1=.00; J2 =.00

PRESENT CYCLE EFFICIENCY = .725

EFF = 72.5%

By changing the diametral pitch (PSUBD1, PSUBD2), the pitch radii of gears (CAPRP1, CAPRP2), the distance from the center of rotation to the center of curvature (ACG1, ACG2) and pivot radius RH02 we are able to get 5% higher eff.

INPUT PARAMETERS

1. PSUBD1 = 99 ; PSUBD2 =99
2. MIN = .372800; MU = 200; RPM = 10,000
3. CAPR1 = ,18687 ; CAPRP2 = .15657
4. RP2 = .04160 ; RP3 = .04160
5. ACG1 = .18687 ; ACG2 = .15657; ACP1-.04160; ACP2=.04160
6. NG1 = 37; NG2 =31; NP2=8; NP3 = 8
7. R1 = .30330; R2 =.20330; R3 =.00000
8. RH0G1 = .02100; RH0G2-.02100; RH0P1 = .00690; RHOP2=.006
9. TG1 = .01610; TG2= .01610; TP1 = .01380; TP2=.01380
10. M1 = .12100E-05; M2= .11100E-05; M3 = .17000E-6
11. RH01 = .013 ; RH02=.005; RH03=.008
12. MD = 0 ; =25.0; PHDOT1 = - 1.0; J1= .00; J2 = 0

CYCLE EFF = .775

EFF = 77.5%

If we keep same inputs as above eccept "MU" (friction COEFF) and, if we change "MU" from .2 to .1, cycle eff is higher for 10% from present cycle eff.

CYCLE EFF = .875

EFF = 87.5%

C) THE FRICTION COEFF, FOR INSTANCE, IS VERY IMPORTANT PARAMETER

By changing friction COEFF, down to .05 (friction COEFF, o TEFLON is .04), Cycle Efficiency of .98 has been reached. The only way to put friction COEFF, under control is by changing material of the gears. But we have to be careful because of the strength of the gears. We can not change material of Gear No. 2 because of High Torque applied to Gear No. 2 and Pinion No. 2. The torque applied to Gear No. 1 is four times less. Also torque applied to Pinion No. 1 and Pinion of the escape wheel is very low. So, we can use for Gear No. 1, Pinion No. 1, and Pinion of the escape wheel material with very low friction COEFF.

FINAL PROPOSAL

1. Build up Gear No. 1, Pinion No. 1, and Pinion of the escape wheel from material with very low friction COEFF. (.04 or less).

2. Build up ogival gear train with input parameter as shown:

MESH NO. 1: GEAR No. 2 AND PINION No. 1

Pd = Diametral Pitch = 99
RP1 = Pitch Radius of Gear = .18687 in
RP2 = Pitch Radius of Pinion = .04160 in
AG1 = Distance from center of rotation to center of curvature (gear) = .18687 in
AP1 = Distance from center of rotation to center of curvature (pinion) = .04160 in
ρG1 = Radius of curvature (gear) = .021 in
ρP1 = Radius of curvature (pinion) = .0069 in
TG1 = Max. thickness (gear) = .0161 in
TP1 = Max. thickness (pinion) = .0138 in
MG1 = Number of teeth (gear) = 37
MP2 = Number of teeth (pinion) = 8
R1 = Distance from center of rotation to center of Gear No. 2 - .30330 in
ρ1 = Gear No. 2 Pivot Radius = .013 in

MESH NO. 2: GEAR NO. 1 and ESCAPE WHEEL PINION

Pd = Diametral Pitch = 99
RP2 = Pitch Radius of Gear = .15657 in
RP3 = Pitch Radius of Pinion = .04160 in
AG2 = Distance from center of rotation to center of curvature (gear) = .15657 in
AP2 = Distance from center of rotation to center of curvature (pinion) = .04160 in
ρG2 = Radius of curvature (gear) = .021 in
ρP2 = Radius of curvature (pinion) = .0069 in
TG2 = Max. thickness (gear) = .0161 in
TP2 = Max. thickness (pinion) = .0138 in

NG2 = Number of Teeth (gear) = 31
NP3 = Number of Teeth (pinion) = 8

R2 = Distance from center of rotation to center of gear No. 1 = .20330 in
R3 = Distance from center of rotation to center of escape wheel = 0 in

ρ_2 = Gear No. 1 Pivot Radius = .005 in
ρ_3 = Escape wheel pivot radius = .008 in

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PSUPD1 =  99.   PSUPD2 =  99.

MIN =  .372800   MU =  .100   RPM =10000.

CAPRP1 =  .18687   CAPRP2 =  .15657

RP2 =  .04160   RP3 =  .04160

ACG1 =  .18687   ACG2 =  .15657   ACP1 =  .04160   ACP2 =  .04160

NG1 =  37.   NG2 =  31.   NP2 =   8.   NP3 =   8.

R1 =  .30330   R2 =  .20330   R3 = 0.00000

RHOG1 =  .02100   RHOG2 =  .02100   RHOP1 =  .00690   RHOP2 =  .00690

TG1 =  .01610   TG2 =  .01610   TP1 =  .01380   TP2 =  .01380

M1 =     .12100E-05   M2 =     .11100E-05   M3 =     .17000E-06

RHO1 =  .013   RHO2 =  .005   RHO3 =  .008

MD =  0.

K =  25.0

PHDOT1 = -1.0

J1 =0.00   J2 =0.00


FP1 =  .04102   FP2 =  .04102

BETA1D =137.9173   BETA2D =228.8664

PSI1T1D = 331.6948   TEST11 =   4.2299
PSI1T2D =  17.4503   TEST12 =  49.9655


PHI1TD =139.4455   PSI1TD =331.6948
PHI1ID =142.7653   PSI1ID =316.7497   PHI1FD =133.0355   PSI1FD =  1.7497


PSI2T2D = 349.7578   TEST21 =  49.5611
PSI2T2D =  34.6640   TEST22 =   4.6549


PHI2TD =227.1556   PSI2TD = 34.6640
PHI2ID =223.0027   PSI2ID = 50.3177   PHI2FD =234.6156   PSI2FD =  5.3177
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PHI1	PHI2	PSI1	PSI2	DPSI1	DPSI2	S1R	S2R	S1F	G1	S2F	G2	POINTEF
142.77	223.00	316.75	50.32	5.	-17.	1.	-1.					.894
142.66	223.45	317.20	48.61	4.	-17.	1.	-1.					.899
142.56	223.91	317.65	46.92	4.	-17.	1.	-1.					.904
142.46	224.36	318.11	45.22	4.	-17.	1.	-1.					.908
142.36	224.81	318.56	43.53	4.	-17.	1.	-1.					.913
142.26	225.26	319.01	41.84	4.	-17.	1.	-1.					.917
142.16	225.71	319.46	40.15	4.	-17.	1.	-1.					.921
142.06	226.16	319.91	38.45	4.	-17.	1.	1.					.923
141.96	226.61	320.36	36.74	4.	-17.	1.	1.					.920
141.86	227.06	320.81	35.03	4.	-17.	1.	1.					.918
141.76	227.51	321.26	33.30	4.	-17.	1.				1.	.041	.915

141.66	227.96	321.71	31.55	4.	-18.	1.				1.	.040	.912
141.56	228.41	322.16	29.78	4.	-18.	1.				1.	.039	.908
141.46	228.86	322.61	27.98	4.	-18.	1.				1.	.039	.905
141.36	229.31	323.06	26.16	4.	-18.	1.				1.	.038	.902
141.26	229.76	323.51	24.34	4.	-18.	1.				1.	.038	.899
141.16	230.21	323.96	22.51	4.	-18.	1.				1.	.037	.896
141.06	230.66	324.41	20.67	4.	-18.	1.				1.	.037	.893
140.96	231.11	324.86	18.84	4.	-18.	1.				1.	.037	.890
140.86	231.56	325.31	17.01	4.	-19.	1.				1.	.036	.887
140.76	232.02	325.76	15.20	4.	-19.	1.				1.	.036	.883
140.66	232.47	326.22	13.41	5.	-18.	1.				1.	.036	.880
140.56	232.92	326.67	11.64	5.	-17.	1.				1.	.036	.877
140.46	233.37	327.12	9.90	5.	-17.	1.				1.	.036	.874
140.35	233.83	327.57	8.20	5.	-17.	-1.				1.	.036	.870
140.25	234.28	328.03	6.53	5.	-16.	-1.				1.	.036	.865
140.15	223.00	328.48	50.32	5.	-17.	-1.	-1.					.913
140.05	223.46	328.93	48.60	5.	-17.	-1.	-1.					.916
139.95	223.91	329.39	46.90	5.	-17.	-1.	-1.					.919
139.85	224.37	329.84	45.19	5.	-17.	-1.	-1.					.922
139.75	224.82	330.30	43.48	5.	-17.	-1.	-1.					.925
139.65	225.28	330.76	41.77	5.	-17.	-1.	-1.					.927
139.55	225.74	331.21	40.05	5.	-17.	-1.	-1.					.930
139.45	226.19	331.67	38.32	5.	-17.	-1.	1.					.929
139.35	226.65	332.13	36.59	5.	-17.		1.	1.	.041			.925
139.25	227.11	332.59	34.84	5.	-18.		1.	1.	.041			.920
139.15	227.57	333.05	33.06	5.	-18.			1.	.041	1.	.040	.915
139.05	228.04	333.52	31.25	5.	-18.			1.	.040	1.	.040	.910
138.95	228.50	333.96	29.41	5.	-19.			1.	.040	1.	.039	.905
138.85	228.97	334.45	27.53	5.	-19.			1.	.040	1.	.039	.900
138.75	229.44	334.92	25.64	5.	-19.			1.	.040	1.	.038	.895
138.65	229.91	335.39	23.73	5.	-19.			1.	.040	1.	.038	.890
138.55	230.38	335.86	21.80	5.	-19.			1.	.040	1.	.037	.884
138.45	230.86	336.34	19.87	5.	-19.			1.	.039	1.	.037	.879
138.35	231.33	336.81	17.94	5.	-19.			1.	.039	1.	.037	.874
138.25	231.81	337.29	16.02	5.	-19.			1.	.039	1.	.036	.869
138.15	232.29	337.77	14.12	5.	-19.			1.	.039	1.	.036	.864
138.04	232.77	338.25	12.23	5.	-19.			1.	.039	1.	.036	.859
137.94	233.25	338.73	10.37	5.	-19.			1.	.039	1.	.036	.854
137.84	233.73	339.21	8.55	5.	-18.			1.	.039	1.	.036	.848
137.74	234.21	339.69	6.77	5.	-18.			1.	.038	1.	.036	.843
137.64	223.00	340.17	50.32	5.	-18.		-1.	1.	.038			.890
137.54	223.49	340.66	48.49	5.	-18.		-1.	1.	.038			.893
137.44	223.97	341.14	46.67	5.	-18.		-1.	1.	.038			.896
137.34	224.46	341.63	44.85	5.	-18.		-1.	1.	.038			.899
137.24	224.94	342.12	43.02	5.	-18.		-1.	1.	.038			.902
137.14	225.43	342.60	41.20	5.	-18.		-1.	1.	.038			.904
137.04	225.92	343.09	39.36	5.	-19.		-1.	1.	.038			.907
136.94	226.40	343.58	37.52	5.	-18.		1.	1.	.038			.903
136.84	226.89	344.06	35.67	5.	-18.		1.	1.	.037			.898
136.74	227.38	344.55	33.81	5.	-19.			1.	.037	1.	.041	.893
136.64	227.87	345.04	31.91	5.	-19.			1.	.037	1.	.040	.888
136.54	228.36	345.53	29.99	5.	-19.			1.	.037	1.	.039	.883
136.44	228.84	346.01	28.05	5.	-19.			1.	.037	1.	.039	.878
136.34	229.33	346.50	26.09	5.	-20.			1.	.037	1.	.038	.873
136.24	229.82	346.99	24.11	5.	-20.			1.	.037	1.	.038	.868
136.14	230.30	347.47	22.13	5.	-20.			1.	.037	1.	.037	.862
136.04	230.79	347.96	20.16	5.	-20.			1.	.037	1.	.037	.857
135.94	231.27	348.44	18.19	5.	-20.			1.	.037	1.	.037	.852
135.84	231.76	348.93	16.24	5.	-19.			1.	.037	1.	.036	.847
135.73	232.24	349.41	14.31	5.	-19.			1.	.036	1.	.036	.842
135.63	232.72	349.89	12.41	5.	-19.			1.	.036	1.	.036	.837
135.53	233.20	350.38	10.54	5.	-18.			1.	.036	1.	.036	.832
135.43	233.68	350.86	8.72	5.	-18.			1.	.036	1.	.036	.827
135.33	234.16	351.34	6.95	5.	-17.			1.	.036	1.	.036	.822
135.23	223.00	351.81	50.32	5.	-18.		-1.	1.	.036			.867
135.13	223.48	352.29	48.52	5.	-18.		-1.	1.	.036			.870

135.03	223.95	352.76	46.74	5.	-18.	-1.	1.	.036			.872
134.93	224.43	353.24	44.96	5.	-18.	-1.	1.	.036			.875
134.83	224.90	353.71	43.20	5.	-18.	-1.	1.	.036			.877
134.73	225.37	354.18	41.43	5.	-18.	-1.	1.	.036			.880
134.63	225.84	354.64	39.67	5.	-18.	-1.	1.	.036			.882
134.53	226.30	355.11	37.91	5.	-18.	1.	1.	.036			.880
134.43	226.76	355.57	36.15	5.	-18.	1.	1.	.036			.875
134.33	227.23	356.04	34.40	5.	-18.		1.	.036	1.	.041	.871
134.23	227.68	356.49	32.63	5.	-18.		1.	.036	1.	.040	.866
134.13	228.14	356.95	30.84	5.	-18.		1.	.036	1.	.040	.861
134.03	228.60	357.41	29.03	5.	-18.		1.	.036	1.	.039	.856
133.93	229.05	357.86	27.22	4.	-18.		1.	.036	1.	.039	.851
133.83	229.50	358.31	25.41	4.	-18.		1.	.036	1.	.038	.847
133.73	229.94	358.75	23.59	4.	-18.		1.	.036	1.	.038	.842
133.63	230.39	359.20	21.78	4.	-18.		1.	.036	1.	.037	.837
133.53	230.83	359.64	19.99	4.	-18.		1.	.036	1.	.037	.832
133.42	231.27	.08	18.21	4.	-18.		1.	.036	1.	.037	.828
133.32	231.70	.51	16.45	4.	-17.		1.	.036	1.	.036	.823
133.22	232.14	.95	14.72	4.	-17.		1.	.036	1.	.036	.818

CYCLE EFFICIENCY = .875

APPENDIX C

EMRALON TIMER SPIN TEST

EMRALON TIMER SPIN TEST DATA SHEET

3-5-82

Two groups of EMRALON treated timers were spin-tested.

Group I. Ten timers with EMRALON coated gear train, with lubricating oil applied on pallet pins only.

Group II. Ten timers with EMRALON coated gear train, with lubricating oil on all required spots specified by standard process specification.

For comparison, control data were taken from spin test result of normal production lot, done recently as routine production monitoring procedure.

COMMENT:

1. Group I timer's pretest had unfavorable beat rates and amplitudes, when running with mainspring before spin test. After applying lubricating oil to pallet pins, beat rates and amplitudes appeared improvement. Comparison data are listed in the following.

	Dry EMRALON	No Oil	EMRALON with oil on pallet pins		
S/N	Beat Rate	Ampl.	Beat Rate	Ampl.	Remark
1	80.74	112	80.59	125	Reject
2	80.89	80	80.72	129	
3	80.76	130	80.74	130	
4	80.86	80	80.75	127	
5	80.77	120	80.67	135	
6	80.81	80	80.65	131	
7	80.89	90	80.83	114	Reject
8	80.89	100	80.78	123	
9	80.67	110	80.59	127	Reject
10	80.81	80	80.72	131	
11	80.82	120	80.76	125	
12	80.75	122	80.61	139	Reject
13	Not Start				Reject
14	80.83	110	80.64	134	
15	80.93	95	80.79	124	
16	80.79	80	80.77	121	
17	80.83	100	80.73	129	

2. Beat rate of EMRALON timers showed a comparably abrupt change when spin rate was shifted from 15K RPM to 22K RPM.

3. Standard deviation of predicted 75 second times was larger for EMRALON timers than standard timers.

3/5/82

EMRALON TIMER SPIN TEST RESULT

GROUP I. Only EMRALON film on gear train, lubricating oil on pallet pins

S/N	PRE-TEST DATA		15K RPM BEAT RATE	PREDICTED 75 SEC. TIME	22K RPM BEAT RATE	24K RPM BEAT RATE	
	BEAT RATE	AMPL.					
2	80.72	129	80.85	74.90	*	*	
3	80.74	130	80.65	75.08	80.65	80.17	
4	80.75	127	80.53	75.20	*	*	
5	80.67	135	80.70	75.04	*	*	
6	80.65	131	80.47	75.25	80.34	*	
10	80.72	131	80.57	75.16	80.07	*	
11	80.76	125	80.74	75.0	80.56	*	
14	80.64	134	80.68	75.06	80.24	*	
15	80.79	124	80.68	75.06	*	*	
17	80.73	129	80.65	75.08	*	*	
$\bar{X}$	80.72	129.5	80.65	75.083			
σ	.049	3.5	.108	.1			

GROUP II. EMRALON film on gear train, lubricating oil on all required spots

S/N	PRE-TEST DATA		15K RPM BEAT RATE	PREDICTED 75 SEC. TIME	22K RPM BEAT RATE	24K RPM BEAT RATE	
	BEAT RATE	AMPL.					
1	80.76	131	80.74	75.0	80.65	*	
3	80.82	132	80.85	74.90	80.86	*	
4	80.73	138	80.61	75.12	*	*	
5	80.77	132	80.74	75.0	80.41	*	
6	80.77	123	80.54	75.19	*	*	
8	80.80	135	80.70	75.04	*	*	
10	80.78	136	80.74	75.0	80.17	*	
13	80.73	133	80.66	75.07	79.41	*	
14	80.81	131	81.01	74.75	*	*	
15	80.77	139	80.82	74.93	80.85	*	
$\bar{X}$	80.77	133	80.64	75.0			
σ	.030	4.5	.240	.122			

*Timer ran but viscorder trace not readable due to excessive noise or poor signal.

STANDARD TIMER SPIN TEST RESULT

ET# 303 LOT # 12-15 TEST DATE: 3-4-82

S/N	PRE-TEST DATA		15K RPM BEAT RATE	PREDICTED 75 SEC. TIME	22K RPM BEAT RATE	24K RPM BEAT RATE
	BEAT RATE	AMPL.				
1	80.64	144	80.62	75.11	80.50	*
2	80.75	132	80.59	75.14	80.49	*
3	80.67	136	80.62	75.11	80.50	*
4	80.76	136	80.59	75.14	80.47	80.34
5	80.76	140	80.74	75.00	80.76	80.70
6	80.69	138	80.56	75.17	*	*
7	80.68	132	80.56	75.17	80.41	*
8	80.84	134	80.74	75.00	80.74	81.14
9	80.72	134	80.61	75.12	80.58	*
10	80.70	140	80.65	75.08	80.47	*
$\bar{X}$	80.72	136.6	80.63	75.104		
σ	.058	3.9	.065	.061		

Used as control group for EMRALON timer spin test

*See preceding page.

APPENDIX D

MAINSPRING EVALUATION

M577 PIP

MAINSPRING EVALUATION

Object: The object of this test program was to evaluate mainsprings with a Vydax surface treatment and springs with a "Bridle" in addition to the Vydax.

Procedure: Because the timer mechanism had a finite life, it was not feasible to repeatedly test the same units with different springs. Therefore ninety new production fuzes were grouped into nine test lots (097- 105). As shown in the chart below, the same ten standard, Vydax, and Vydax/Bridle springs were each used in three of the lots. All springs were serialized to permit traceability throughout the testing.

TEST COND.	CONCENTRIC 150 SEC.			.030 ECCENTRIC 150 SEC.			.030 ECCENTRIC 175 SEC.		
LOT / SPRING	097	098	099	100	101	102	103	104	105
STD.	X			X			X		
VYDAX		X			X			X	
V/BRIDLE			X			X			X

Static torque data was obtained for the twenty special mainsprings. They are given on p. 85 of the data sheets. Each lot (except 104 and 105) was tested for beat rate three times: statically, rotated at 15,000 rpm, and rotated at 22,000 rpm. The runs were identified as "-0", "-1", and "-2" respectively.

Analysis: During spin tests, beat rate information was recorded on tape in the form of a "sawtooth" shaped repeating pattern. Using a conversion chart, the width of a "tooth" was correlated with the beat rate.

To reduce the approximately 800 feet of tape to a more tractable and quantifiable form, the following computations were performed. For every tape, each cycle (i.e. "tooth") width was measured and tabulated. The mean value and sigma (σ) were obtained and converted into mean beat rate ($\overline{BR}$), $\overline{BR}$ $+\sigma$, and $\overline{BR}$ $-\sigma$. For every test fuze, the difference between $\overline{BR}$ $+\sigma$ and $\overline{BR}$ $-\sigma$ was tabulated as a "Roughness Factor" (RF). Lastly, for every test lot run, an average Roughness Factor ($\overline{RF}$) was calculated.

The data for lots 097 through 105 are given in data sheets pp. 86-92. To facilitate the presentation, the following codes were used:

a. All values were recorded in hundredths of a hertz. The "80" was omitted.

b. The symbol "Fast/Slow" meant that the BR crossed over the nominal 80.74. Under these conditions, the computation and interpretation of σ was not useful.

c. The symbol "N" meant that σ was greater than $\overline{BR}$. It was the mathematical result of using highly skewed data. This occurred when the beat rate varied drastically in a non uniform manner.

After analyzing the data based on the entire running time of the fuze, it was decided to repeat the computations using only the last fifty seconds running time. The data are given in data sheets pp. 93-99.

To assist in comparing mainspring performance, an additional calculation was performed. For each spring type, the number of spin test "incompletes" to the total number of spin tests was computed in percent. An "incomplete" meant that the fuze did not start, quit, went from fast to slow, or showed excessive standard deviation. The study was made for all spin tests and repeated for only the eccentric runs. The data are presented on data sheet p. 100.

Results: Previously reported test data from the spring manufacturer and preliminary studies at BSIC had been encouraging. Therefore the program described above was instituted to obtain sufficient information on which to base hardware decisions.

Reviewing the static torque data (p. 85), it can be seen that the bridle spring developed an initial torque averaging about 1.3 in-oz higher than the Vydax spring. Moreover the torque dropoff at 4 3/4 turns was almost 1 in-oz less for the bridle compared to the Vydax. This flatter "discharge" characteristic of the bridle spring provided a more constant torque to the mechanism than either the Vydax or standard mainspring.

In examining the Roughness Factors, it should be noted that, for an ideal fuze, the BR would remain constant at 80.74 for the entire running time. Thus, ideally, σ and RF would be zero. Therefore $\overline{RF}$ can be used as a figure of merit in comparing lot performance; the smaller the number, the more uniform the beat rate.

Referring to the $\overline{RF}$ values obtained for the entire running time (p. 92), no mainspring type showed any clear cut advantage. However the RF values using the last fifty seconds of running time were considered more significant because, in that region, the mainspring torque was lower. Examination of the data (P. 99) revealed that, for concentric runs, the Vydax and bridle spring fuzes showed considerably better performance. In eccentric spin tests, all springs were comparable at low speed, but at high speed, the bridle was clearly superior.

The results were also viewed from another perspective. The ratio of spin test incompletes (i.e. no start, quit, fast/slow or excessive σ) to total spin tests was computed (p. 100). It shows that the standard fuzes performed worst, the bridle fuzes better, and the Vydax fuzes, by far, the best.

<u>Conclusion:</u> Evaluation of the mainspring test results does not clearly demonstrate the superiority of the bridle or Vydax under all conditions. Economic considerations may be a deciding factor.

MAINSPRING TORQUE

A. VYDAX

S/N \ TURN	7 3/4	6 3/4	5 3/4	4 3/4
1	31	29	28	26
2	31	29	27 1/2	25 1/2
3	32	30 1/2	28 1/2	26 1/2
4	31	29	27	25
5	31	30	28 1/2	27
6	32	30	28	26
7	30 1/2	29	28	26
8	32	29	27	25
9	31 1/2	30	28	26 1/2
10	32	29 1/2	28	26

B. BRIDLE + VYDAX

S/N \ TURN	7 3/4	6 3/4	5 3/4	4 3/4
1	32 1/2	31	29 1/2	28
2	32 1/2	31	29 1/2	28
3	33	31	29 1/2	28
4	32 1/2	31	29 1/2	28
5	34	31 1/2	30	28 1/2
6	33 1/2	31 1/2	30	28
7	32	31	29 1/2	28
8	32 1/2	31	30	28
9	32	31	29 1/2	28
10	32 1/2	31	29 1/2	28

MAINSPRING EVALUATION

SPIN TEST AT CONCENTRIC, 150 SECONDS. DATA TAKEN OVER TOTAL RUNNING TIME.

LOT NO.	S/N	-0(STATIC)	-1 (15,000 RPM SPIN RATE)			-2 (22,000 RMP SPIN RATE)			REMARKS
		BR	$\overline{BR}$	$\overline{BR}+\sigma$	$\overline{BR}-\sigma$	$\overline{BR}$	$\overline{BR}+\sigma$	$\overline{BR}-\sigma$	
097 STD SPRING	1	66	55	60	43	17	33	79.82	
	2	74	67	70	N	37	60	N	
	3	73	66	70	79.32	53	64	N	
	4	64	67	70	55	51	54	46	
	5	80	54	61	32	46	50	39	
	6	76	62	66	49	38	58	N	
	7	76	64	67	60	39	53	79.66	
	8	79	70	71	68	55	61	42	
	9	70	17	41	77.83	-	-	-	Quit at 150 sec. (-1)
	10	72	43	60	N	-	-	-	Quit at 7 sec. (-2)
098 VYDAX SPRING	1	70	70	71	67	69	70	66	
	2	80	49	51	45	61	63	58	
	3	68	64	65	63	47	50	43	
	4	82	65	69	45	-	-	-	No Start (-2)
	5	66	62	63	60	60	62	58	
	6	76	67	68	65	43	46	40	
	7	80	64	66	61	79.97	20	79.30	
	8	76	58	60	56	64	68	05	
	9	72	53	54	52	79.98	25	79.02	
	10	76	49	51	45	65	66	64	

To Be Cont'd.

MAINSPRING EVALUATION

CONTINUE

LOT NO.	S/N	-0(STATIC)	-1 (15,000 RPM SPIN RATE)			-2 (22,000 RMP SPIN RATE)			REMARKS
		BR	$\overline{BR}$	$\overline{BR} + \sigma$	$\overline{BR} - \sigma$	$\overline{BR}$	BR $+\sigma$	BR $-\sigma$	
099	1	72	62	63	61	55	62	53	
VYDAX	2	72	62	63	60	40	45	30	
&	3	64	57	59	54	10	23	79.90	
BRIDLE SPRING	4	78	74	74	74	56	61	45	
	5	72	61	62	59	09	20	-	Started 50 sec. Late (-2)
	6	74	66	67	63	18	27	03	
	7	74	44	52	33	-	-	-	Quit at 100 sec. (-1)
	8	72	58	63	44	-	-	-	No Start (-2)
	9	82	65	66	64	60	66	79.79	
	10	72	48	57	19	-	-	-	No Start (-2)
	1								
	2								
	3								
	4								
	5								
	6								
	7								
	8								
	9								
	10								

MAINSPRING EVALUATION

SPIN TEST AT .030 ECCENTRIC, 150 SECONDS, DATA TAKEN OVER TOTAL RUNNING TIME.

LOT NO.	S/N	-0(STATIC)	-1 (15,000 RPM SPIN RATE)			-2 (22,000 RMP SPIN RATE)			REMARKS
		BR	$\overline{BR}$	$\overline{BR} + \sigma$	$\overline{BR} + \sigma$	$\overline{BR}$	$\overline{BR} + \sigma$	$\overline{BR} - \sigma$	
100 STD. SPRING	1	74	39	44	32	-	-	-	Fast/Slow (-2)
	2	80	89	88	89	82.41	82.41	82.41	
	3	82	59	63	47	81.64	81.64	81.64	
	4	68	98	95	81.01	81.01	85	N	Quit at 90 Sec. (-2)
	5	64	79.79	79.90	79.68	02	10	79.92	
	6	68	57	63	32	-	-	-	Fast/Slow (-2)
	7	74	44	47	40	81.38	81.31	81.48	
	8	74	52	54	48	-	-	-	Fast/Slow (-2)
	9	74	68	70	65	81.21	81.16	81.28	
	10	72	77	76	78	81.03	99	81.07	
101 VYDAX SPRING	1	80	81.12	81.10	81.15	-	-	-	Quit at 42 Sec. (-2)
	2	82	71	73	41	81.16	81.89	81.25	
	3	84	61	63	58	85	82	90	
	4	80	53	55	49	82.07	82.07	82.07	
	5	82	09	18	79.99	79.57	79.79	79.23	
	6	74	84	82	87	81.54	81.54	81.54	
	7	84	46	49	44	79.97	09	79.82	
	8	64	17	24	08	-	-	-	Fast/Slow (-2)
	9	74	54	56	49	56	61	46	
	10	82	81.16	81.13	81.21	81.27	81.22	81.31	

/ To be cont'd

MAINSPRING EVALUATION

Continue

LOT NO.	S/N	-0(STATIC)	-1 (15,000 RPM SPIN RATE)			-2 (22,000 RMP SPIN RATE)			REMARKS
		BR	$\overline{BR}$	$\overline{BR}+\sigma$	$\overline{BR}-\sigma$	$\overline{BR}$	$\overline{BR}+\sigma$	$\overline{BR}-\sigma$	
102 VYDAX & BRIDLE SPRING	1	80	57	59	55	10	15	04	
	2	72	52	54	50	79.76	79.86	79.56	
	3	84	65	67	63	-	-	-	Unstable at 90 Sec. (-2)
	4	66	64	67	57	-	-	-	Quit at 90 Sec. (-2)
	5	76	69	70	64	81.40	81.24	81.70	
	6	74	-	-	-	-	-	-	Fast/Slow (-1) No Start (-2)
	7	80	36	40	33	81.74	81.60	81.96	
	8	80	81.02	81.01	81.03	81.72	81.58	81.94	
	9	64	26	29	23	29	34	21	
	10	72	53	55	50	38	97	79.95	
	1								
	2								
	3								
	4								
	5								
	6								
	7								
	8								
	9								
	10								

MAINSPRING EVALUATION

SPIN TEST AT .030 ECCENTRIC, 175 SECONDS, DATA TAKEN OVER TOTAL RUNNING TIME.

LOT NO.	S/N	-0(STATIC)	-1 (15,000 RPM SPIN RATE)			-2 (22,000 RMP SPIN RATE)			REMARKS
		BR	$\overline{BR}$	$\overline{BR} + \sigma$	$\overline{BR} - \sigma$	$\overline{BR}$	$\overline{BR} + \sigma$	$\overline{BR} - \sigma$	
103 STD. SPRING	1	80	38	56	N				79.41 Constant (-2)
	2	76	87	83	95				Fast/Slow (-2)
	3	72	81.01	99	81.02				Quit at 47 Sec. (-2)
	4	70	39	47	23				Quit at 95 Sec. (-2)
	5	72	49	53	43				78.74 Constant (-2)
	6	80	68	70	62				Quit at 106 Sec. (-2)
	7	72	-	-	-				Unstable at 30 Sec.(-1) Quit at 56 Sec. (-2)
	8	72	87	85	88				Quit at 87 Sec. (-2)
	9	78	81.07	81.04	81.12				Quit at 12 Sec. (-2)
	10	64	74	74	74				Quit at 31 Sec. (-2)
104 VYDAX SPRING	1	76	68	70	67				
	2	78	-	-	-				Fast/Slow (-1)
	3	80	31	38	20				
	4	68	81.00	98	81.03				
	5	82	17	22	09				
	6	76	57	63	43				
	7	72	-	-	-				Fast/Slow (-1)
	8	68	63	66	59				
	9	74	68	71	N				
	10	72	81.41	81.41	81.41				

To be continued

MAINSPRING EVALUATION

Continued

LOT NO.	S/N	-0(STATIC)	-1 (15,000 RPM SPIN RATE)			-2 (22,000 RMP SPIN RATE)			REMARKS
		BR	$\overline{BR}$	$\overline{BR} + \sigma$	$\overline{BR} - \sigma$	$\overline{BR}$	$\overline{BR} + \sigma$	$\overline{BR} - \sigma$	
105 VYDAX & BRIDLE SPRING	1	70	58	61	54				
	2	76	84	82	85				
	3	76	38	41	34				
	4	64	68	70	65				
	5	70	57	62	46				
	6	78	-	-	-				Fast/Slow (-1)
	7	70	67	68	66				
	8	72	-	-	-				Fast/Slow (-1)
	9	64	67	67+	67-				
	10	74	15	25	00				
	1								
	2								
	3								
	4								
	5								
	6								
	7								
	8								
	9								
	10								

MAINSPRING ROUGHINESS FACTOR (RF)

DATA TAKEN OVER TOTAL RUNNING TIME

S/N	LOT NUMBER							
	097-1	097-2	098-1	098-2	099-1	099-2	100-1	100-2
1	17	51	4	4	2	9	12	-
2	N	N	6	5	3	15	1	0
3	138	N	2	7	5	33	16	0
4	15	8	24	-	0	16	6	N
5	29	11	3	4	3	-	22	18
6	17	N	3	6	4	24	29	-
7	7	87	5	90	19	-	7	17
8	3	19	4	63	19	-	6	-
9	258	-	2	123	2	87	5	12
10	N	-	6	2	38	-	2	8
$\overline{RF}$	60.5	35.2	5.9	33.6	9.5	30.7	10.6	13.8

S/N	LOT NUMBER							
	101-1	101-2	102-1	102-2	103-1	103-2	104-1	105-1
1	5	-	[illegible]	11	N	-	3	7
2	32	16	4	30	12	-	-	3
3	5	8	4	-	3	-	18	7
4	6	0	10	-	24	-	5	5
5	19	56	6	46	10	-	13	16
6	5	0	-	-	7	-	20	-
7	5	27	7	36	-	-	-	2
8	16	-	2	36	3	-	7	-
9	7	15	6	13	8	-	N	0
10	8	9	5	52	0	-	0	25
$\overline{RF}$	10.8	16.4	5.3	32	8.4	-	9.4	8.1

MAINSPRING EVALUATION

SPIN TEST AT CONCENTRIC, 150 SECOND, DATA TAKEN OVER LAST 50 SECONDS ONLY.

LOT NO.	S/N	-0(STATIC)	-1 (15,000 RPM SPIN RATE)			-2 (22,000 RMP SPIN RATE)			REMARKS
		BR	$\overline{BR}$	$\overline{BR} + \sigma$	$\overline{BR} - \sigma$	$\overline{BR}$	$\overline{BR} + \sigma$	$\overline{BR} - \sigma$	
097 STD SPRING	1	66	47	49	44	79.95	05	79.79	
	2	74	53	61	19	01	11	79.94	
	3	73	59	64	48	53	64	N	
	4	64	63	63+	63-	51	55	46	
	5	80	41	53	79.94	40	43	36	
	6	76	60	62	57	04	19	79.82	
	7	76	62	64	57	14	21	07	
	8	79	69	69+	68	45	49	40	
	9	70	79.83	79.95	79.68	-	-	-	Quit at 150 sec. (-1)
	10	72	21	31	02	-	-	-	Quit at 7 sec. (-2)
098 VYDAX SPRING	1	70	70	70+	69	67	68	64	
	2	80	50	52	49	59	61	55	
	3	68	65	66	64	44	47	42	
	4	82	59	60	57	-	-	-	No Start (-2)
	5	66	60	62	59	61	61	60	
	6	76	66	67	64	42	45	38	
	7	80	62	64	56	79.57	79.75	79.43	
	8	76	56	57	55	68	71	42	
	9	72	52	53	51	79.74	79.74	79.74	
	10	76	46	48	44	64	65	63	

To Be Cont'd.

AD-A134 741 M577 FUZE PRODUCT IMPROVEMENT PROGRAM SIMPLIFIED TIMER STOP AND INCREASIN..(U) BULOVA SYSTEMS AND INSTRUMENTS CORP VALLEY STREAM N Y S H NG ET AL. OCT 83 2/2

UNCLASSIFIED ARLCD-CR-83037 DAAK10-81-C-0067 F/G 19/1 NL

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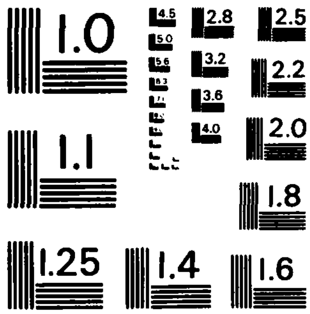


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

MAINSPRING EVALUATION

CONTINUED

LOT NO.	S/N	-0(STATIC)	-1 (15,000 RPM SPIN RATE)			-2 (22,000 RMP SPIN RATE)			REMARKS
		BR	$\overline{BR}$	$\overline{BR}+\sigma$	$\overline{BR}-\sigma$	$\overline{BR}$	$\overline{BR}+\sigma$	$\overline{BR}-\sigma$	
099 VYDAX & BRIDLE SPRING	1	72	61	61	60	54	54	53	
	2	72	60	61	60	34	34	32	
	3	64	57	59	55	79.99	06	79.92	
	4	78	74	74	74	48	52	43	
	5	72	61	62	60	07	07	07	Start 50 seconds late (-2)
	6	74	63	65	61	06	09	03	
	7	74	-	-	-	-	-	-	Quit at 100 sec. (-1)
	8	72	48	53	40	-	-	-	No start (-2)
	9	82	64	65	63	44	50	33	
	10	72	31	40	13	-	-	-	No start (-2)
	1								
	2								
	3								
	4								
	5								
	6								
	7								
	8								
	9								
	10								

MAINSPRING EVALUATION

SPIN TEST AT .030 ECCENTRIC, 150 SECONDS. DATA TAKEN OVER LAST 50 SECONDS ONLY

LOT NO.	S/N	-0(STATIC)	-1 (15,000 RPM SPIN RATE)			-2 (22,000 RMP SPIN RATE)			REMARKS
		BR	$\overline{BR}$	BR +σ	BR -σ	$\overline{BR}$	BR +σ	BR -σ	
100 STD SPRING	1	74	39	44	29	79.80	04	79.21	
	2	80	89	89	89	82.41	82.41	82.41	
	3	82	53	57	46	81.68	81.66	81.70	
	4	68	94	93	96	-	-	-	Quit at 90 sec. (-2)
	5	64	79.74	79.74	79.74	79.95	00	79.87	
	6	68	44	53	25	79.44	79.77	78.76	
	7	74	40	43	35	81.31	81.28	81.36	
	8	74	49	51	47	-	-	-	Fast/Slow (-2)
	9	74	66	67	66	81.18	81.14	81.25	
	10	72	77	77	78	98	96	81.02	
101 VYDAX SPRING	1	80	81.14	81.14	81.14	-	-	-	Quit at 42 sec. (-2)
	2	82	70	72	34	81.10	81.04	81.21	
	3	84	63	63	62	81	80	85	
	4	80	50	53	46	82.07	82.07	82.07	
	5	82	00	11	79.89	79.41	79.41	79.41	
	6	74	82	80	85	81.54	81.54	81.54	
	7	84	45	47	43	79.88	79.99	79.76	
	8	64	12	18	04	19	32	79.94	
	9	74	49	51	46	50	53	46	
	10	82	81.12	81.10	81.14	81.29	81.26	81.33	

To Be Cont'd.

MAINSPRING EVALUATION

CONT'D.

LOT NO.	S/N	-0(STATIC)	-1 (15,000 RPM SPIN RATE)			-2 (22,000 RMP SPIN RATE)			REMARKS
		BR	$\overline{BR}$	$\overline{BR}+\sigma$	$\overline{BR}-\sigma$	$\overline{BR}$	$\overline{BR}+\sigma$	$\overline{BR}-\sigma$	
102 VYDAX & BRIDLE SPRING	1	80	57	59	57	07	07	07	
	2	72	50	51	48	79.74	79.74	79.74	
	3	84	64	65	63	-	-	-	Unstable at 90 sec(-2)
	4	66	59	62	53	-	-	-	Quit at 90 Sec. (-2)
	5	76	71	71	70	81.27	81.17	81.40	
	6	74	79.99	11	79.82	-	-	-	No start (-2)
	7	80	36	39	34	81.74	81.74	81.74	
	8	80	81.01	81.01	81.01	81.72	81.66	81.81	
	9	64	24	25	22	24	25	21	
	10	72	50	51	49	28	45	48	
	1								
	2								
	3								
	4								
	5								
	6								
	7								
	8								
	9								
	10								

MAINSPRING EVALUATION

SPIN TEST AT .030 ECCENTRIC, 175 SECONDS. DATA TAKEN OVER LAST 50 SECONDS ONLY.

LOT NO.	S/N	-0(STATIC)	-1 (15,000 RPM SPIN RATE)			-2 (22,000 RMP SPIN RATE)			REMARKS
		BR	$\overline{BR}$	BR +σ	BR -σ	$\overline{BR}$	BR +σ	BR -σ	
103 STD SPRING	1	80	26	32	20	79.41	79.41	79.41	
	2	76	84	80	00	36	49	79.94	
	3	72	99	98	00	-	-	-	Quit at 47 sec. (-2)
	4	70	25	34	09	-	-	-	Quit at 95 sec. (-2)
	5	72	43	49	36	78.74	78.74	78.74	
	6	80	65	67	63	-	-	-	Quit at 106 sec. (-2)
	7	72	-	-	-	-	-	-	Unstable after 30 sec. Quit at 56 sec. (-2)
	8	72	63	63	63	-	-	-	Quit at 87 sec (-2)
	9	78	81.10	81.11	81.12	-	-	-	Quit at 12 sec. (-2)
	10	64	74	74	74	-	-	-	Quit at 31 sec. (-2)
104 VYDAX SPRING	1	76	67	69	65				
	2	78	-	-	-				Fast/Slow (-1)
	3	80	20	28	09				
	4	68	81.03	81.02	81.04				
	5	82	10	17	02				
	6	76	47	53	40				
	7	72	59	61	56				
	8	68	59	62	56				
	9	74	62	63	60				
	10	72	81.41	81.41	81.41				

To Be Cont'd.

MAINSPRING EVALUATION

CONT'D.

LOT NO.	S/N	-0(STATIC)	-1 (15,000 RPM SPIN RATE)			-2 (22,000 RMP SPIN RATE)			REMARKS
		BR	$\overline{BR}$	$\overline{BR}+\sigma$	$\overline{BR}-\sigma$	$\overline{BR}$	$\overline{BR}+\sigma$	$\overline{BR}-\sigma$	
105 VYDAX & BRIDLE SPRING	1	70	55	59	50				
	2	76	82	81	82				
	3	76	34	36	32				
	4	64	67	67	65				
	5	70	49	53	44				
	6	78	-	-	-				Fast/Slow (-1)
	7	70	66	66	65				
	8	72	55	59	48				
	9	64	67	67	66				
	10	74	00	10	79.86				
	1								
	2								
	3								
	4								
	5								
	6								
	7								
	8								
	9								
	10								

MAINSPRING ROUGHNESS FACTOR (RF)

DATA TAKEN OVER LAST 50 SECONDS ONLY.

S/N	LOT NUMBER							
	097-1	097-2	098-1	098-2	099-1	099-2	100-1	100-2
1	5	26	1	4	1	1	15	83
2	42	17	3	6	1	2	0	0
3	16	N	2	5	4	14	11	4
4	0	9	3	-	0	9	3	-
5	59	7	3	1	2	0	0	13
6	5	37	3	7	4	6	28	101
7	7	14	8	32	-	-	8	8
8	1	9	2	29	13	-	4	-
9	27	-	2	0	2	17	1	11
10	29	-	4	2	27	-	1	6
$\overline{RF}$	19.1	17.0	3.1	9.6	6.0	6.1	7.1	28.2

S/N	LOT NUMBER							
	101-1	101-2	102-1	102-2	103-1	103-2	104-1	105-1
1	0	-	2	0	12	0	4	9
2	38	17	3	0	80	55	-	1
3	1	5	2	-	98	-	19	4
4	7	0	9	-	25	-	2	2
5	22	0	1	23	13	0	15	9
6	5	0	29	-	4	-	13	-
7	4	23	5	0	-	-	5	1
8	14	38	0	15	0	-	6	11
9	5	7	3	4	0	-	3	1
10	4	7	2	3	1	-	0	24
$\overline{RF}$	10.0	10.2	5.6	6.4	25.9	-	7.4	6.9

SPIN TEST PERFORMANCE

INCOMPLETE/TOTAL RUNS

	STD SPRING		VYDAX SPRING		VYDAX/BRIDLE SPRING	
ALL TESTS	26%	(13/50)	12%	(6/50)	20%	(10/50)
.030 ECCENTRIC (150 SEC ONLY)	45%	(9/20)	15%	(3/20)	35%	(7/20)

APPENDIX E

SLEEVE STRENGTH TEST

E1. SLEEVE STRENGTH TEST

Original data published in September 1981 and October 1981 progress reports, rewritten for final report.

A. TENSILE STRENGTH STATIC LOAD TEST

Date of Test: September 11, 1981

Object: The object of the test was to obtain the static ultimate strength of the sleeve.

Configuration: The configuration consisted of five sleeves with internal groove simulating the thread-relief of the threaded sleeve design. Four regular production sleeves were used for the control group.

Procedure: Sleeves were placed, one at a time, in the Tinius Olsen tester. Load was applied to the inner base step of the sleeve and was increased at the table speed of 0.020 in/min until the sleeve ruptured.

Result:

Test Group (a)

S/N	Rupture pt. Lb. Force	Defl. in
1	14, 300	*
2	15, 350	.021
3	14, 550	.028
4	14, 725	.026
5	14, 125	.025
$\bar{X}$	14, 610	
σ	423	

Control Group (b)

S/N	Rupture pt. Lb. Force	Defl. in
A	14.250	*
B	12.875	.020
C	16.475	.028
D	14.475	.024
$\bar{X}$	14.518	
σ	1.284	

*Data not obtained

(a) 4 units cracked at groove, 1 at base step.
(b) All units cracked at base step.

B. AIR GUN TEST

Date of Test: October 22, 1981

Object: The object of the test was to observe the sleeve response to simulate the shooting setback force.

Configuration: The configuration consisted of seven sleeves with the internal groove simulating thread-relief of threaded sleeve design. Four standard production sleeves were used for the control group.

Procedure: Sleeves were assembled in inert fuzes, which is the standard package for air gun shooting. Tested units were reclaimed for inspection.

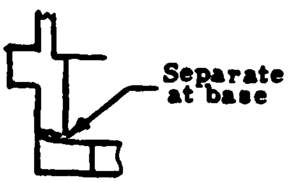
Results:

S/N	Sleeve Configur.	Test Temp.	Test Force (g)	Sleeve conditions after Test
1	Grooved	Ambient	31542	Fracture at base of sleeve, separate
2	Grooved	Ambient	31192	Crack at base of sleeve, not separate
3	Grooved	Ambient	27182	Intact, slight crease at base
4	Grooved	Ambient	22225	Intact
5	Grooved	-40°C	20684	Intact
6	Grooved	-40°C	24511	Intact
7	Grooved	-40°C	25531	Crack at base, no separation
8	Standard	Ambient	26709	Crack at base, no separation
9	Standard	Ambient	26765	Crack at base, no separation
10	Standard	-40°C	25640	Crack at base, no separation
11	Standard	-40°C	25466	Intact

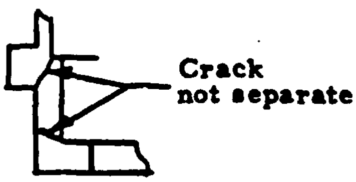
E2. SLEEVE STATIC TEST SUMMARY

FEBRUARY 1982

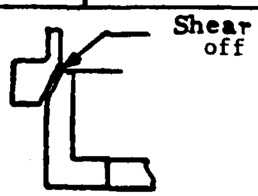
TYPE OF SLEEVE	S/N	HARDNESS BHN	WALL THICKNESS	RUPTURE LB-FORCE	EQUIV. STRESS LB/SQ.IN.	FEATURES OF RUPTURE
Group I Bulova sleeves with u'cut at base non heat treated	A1	135	.0732	15,500	42,735	Sketch 1
	A2	137	.0724	13,750	38,376	Sketch 1
	A3	137	.0730	11,500	31,838	Sketch 1
	A4	140	.0730	12,425	34,352	Sketch 1
	A5	140	.0732	13,500	37,221	Sketch 1
	A6	146	.0732	11,325	31,241	Sketch 1
	$\bar{X}$	139	.0730	13,000	35,961	
	σ	3.87	.00030	1,578	4,363	
	Max.	146	.0732	15,500	42,735	
	Min.	135	.0724	11,325	31,241	
Group II Bulova sleeves without u'cut non heat treated	63	137	.0727	16,350	45,429	Sketch 1
	64	137	.0734	15,780	43,435	Sketch 1
	65	135	.0728	13,350	37,063	Sketch 1
	66	140	.0730	15,850	43,845	Sketch 1
	67	142	.0735	16,160	44,420	Sketch 2
	68	135	.0734	15,950	43,903	Sketch 3
	X	138	.0731	15,573	43,016	
	σ	2.8	.00034	1,109	2,996	
	Max.	142	.0735	16,350	45,429	
	Min.	135	.0727	13,350	37,063	
Group III Hamilton sleeves non heat treated	81	140	.0735	16,000	44,004	Sketch 1
	82	133	.0727	15,125	42,002	Sketch 1
	83	145	.0728	15,575	43,180	Sketch 1
	84	142	.0730	16,500	45,656	Sketch 1
	85	137	.0733	16,375	45,135	Sketch 1
	86	140	.0732	16,200	44,690	Sketch 1
	$\bar{X}$	140	.0731	15,963	44,111	
	σ	4.14	.00031	523	1,349	
	Max.	145	.0735	16,500	45,656	
	Min.	133	.0727	15,125	42,002	



Sketch 1



Sketch 2

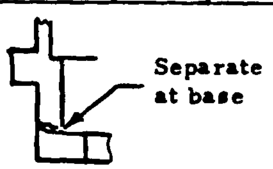


Sketch 3

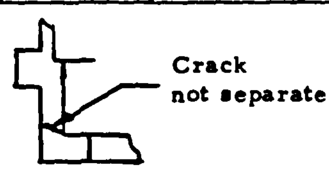
E3. SLEEVE STATIC TEST SUMMARY

MARCH 1982

Types of Sleeve	S/N	Wall Thickness	BHN Before Heat-Treat	BHN After Heat-Treat	Rupture Point lb-Force	Equiv. Stress lb/sq in	Feature of Rupture
Group IV	F7	.075	137	133	13,250	36,500	Sketch 1
Bulova regular	F8	.074	133	130	13,300	36,640	Sketch 2
sleeve heat	F9	.074	122	122	13,000	35,810	Sketch 1
treated at	F10	.074	126	125	12,000	33,060	Sketch 1
350°F 4 hours							
	$\overline{X}$	.0743	129.5	127.5	12,887	35,502	
	σ	.0005	6.76	4.93	606	1,668	
	MAX.	.075	137	133	13,300	36,640	
	MIN.	.074	122	122	12,000	33,060	
Group V	G7	.075	128	110	13,750	37,880	Sketch 1
Bulova regular	G8	.075	126	118	12,500	34,440	Sketch 1
sleeve heat	G9	.074	133	120	14,600	40,220	Sketch 2
treated at	G10	.074	130	118	9,380	25,840	Sketch 1
150°F 4 hours							
	$\overline{X}$	.0745	129.3	116.5	12,558	3[illegible],595	
	σ	.0006	2.97	4.43	2,287	6,300	
	MAX.	.075	133	120	14,600	40,220	
	MIN.	.074	126	110	9,380	25,840	
Group VI	F11	.075	128	-	14,250	39,260	Sketch 2
Bulova regular	G11	.074	124	-	12,570	34,630	Sketch 1
sleeve							
non heat treated							
	$\overline{X}$	.0745	126	-	13,410	36,945	



Sketch 1



Sketch 2

E4. AIR GUN TEST REPORT

Date of test: 4-23-1982

This air gun test was part of M577 fuze Product Improvement Program. It included two tests. The first test connected to sleeve strength improvement, for evoluation of sleeve heat treated at 350° F, 4 hours and at 450°F, 4 hours. The second test was planned to evaluate the alternative arrangement of trigger assembly support that changed the form of setback force distribution on sleeve, trigger assembly, SSD and support washer. Following are results of these tests.

TEST 1. EVALUATION OF HEAT TREATED SLEEVE

Test Samples: Six M577 fuzes, regular assembly with heat treated sleeves which were sampled from current production lot.

Air Gun Test Results:

Group 1. Sleeves heat treated at 350° F, 4 hours.

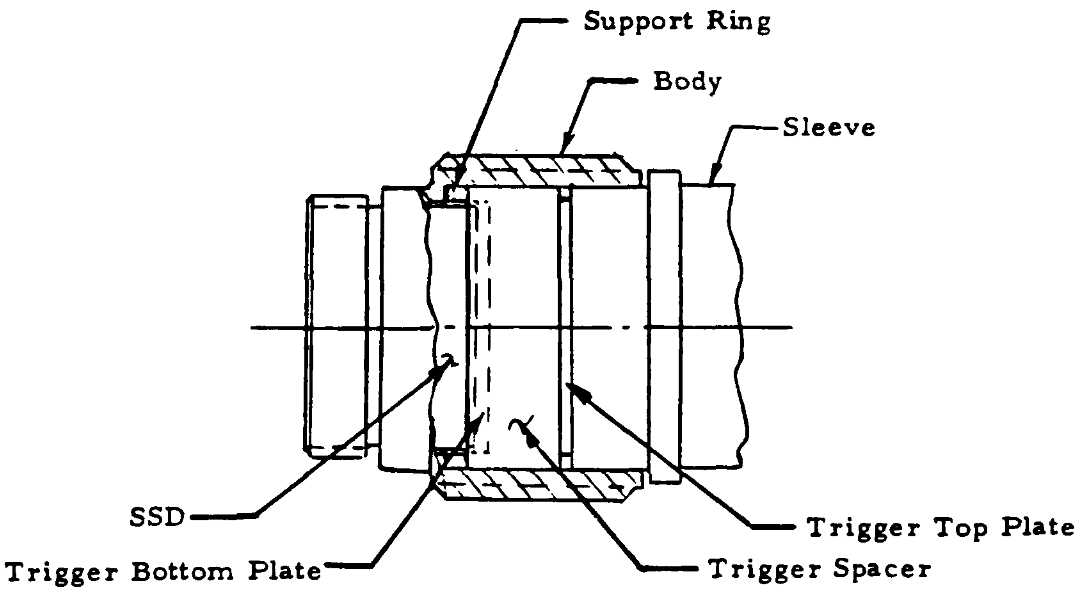
S/N	BHN Before Heating	BHN After Heating	Setback g	Parts conditions
F1	137	133	33,617	Sleeve broken at base; SSD bottom plate bent against rotor, jamming mechanism; Support Washer buckled.
F2	128	128	30,601	Sleeve broken at base; SSD bottom plate bent against rotor, jamming mechanism; Support Washer buckled.
F3	135	133	21,750	Sleeve intact with very insignificantly stressed at local spot; Trigger Assembly mounting screws (1) loosened 3 turns, (2) lost torque; SSD intact, functioning, timing 1.00 seconds; Support Washer in good shape.

Group 2. Sleeves heat treated at 450° F, 4 hours

S/N	BHN Before Heating	BHN After Heating	Setback g	Parts conditions
G1	130	118	27,966	Sleeve intact, slightly necked down; Trigger Assembly mounting scre , (2) lost torgue, (1) loosened 4-5 turns; SSD intact, functioning, timing 1.19 seconds; Support Washer good.
G2	137	126	29,088	Sleeve intact, slightly distorted on the side opposite to loosened screw; Trigger Assembly mounting screws; (2) lost torgue, (1) loosened 4 turns; SSD intact, functioning, timing 1.03 seconds; Support Washer good.
G3	133	120	30,665	Sleeve distorted with interference to body fit, but no fracture observed; Trigger Assembly mounting screws (1) lost torgue, (2) tight; SSD rotor and gear train jammed; Support Washer in good shape.

TEST 2: EVALUATION OF ALTERNATIVE TRIGGER ASSEMBLY SUPPORT

Test Samples: Two M577 Fuzes with modified Trigger Spacer and Body, arranged as shown in the sketch. The setback force reaction exerts to the 3-Module Assembly on the support edge of the Trigger Spacer in the form of compression. The compressive stress on a solid support presumably creates less part deformation, therefore, allowing the module functioning at higher g. This arrangement is referred to as high g trigger.



Air Gun Test Results:

S/N	Setback g	Parts Conditions
A	30,474	Ogive to Body torque lost; Support Washer good; SSD intact, functioning, timing 1.07 seconds; Sleeve without significant change; Trigger Assembly intact with Trigger Spacer Support edge compressed; mounting screw (1) lost torque; Setback Pin came out.
B	30,474	This Trigger Spacer had been tested with 20,000 lb static load before assembled in fuze. After air gun test: Ogive to Body torque lost; Support Washer good; SSD intact, functioning, timing 1.02 seconds; Sleeve without noticeable change; Trigger Assembly good, mounting screws tight.

DISCUSSION:

1. For regular fuze assembly, at setback force of 30,000 g or higher, sleeve deformed significantly. Two out of three units tested at this g level had cracked sleeve. The remaining one had a sleeve seriously distroted. The lower wall of the sleeve is stressed under setback action, because that part of sleeve loaded tensilely by the weight of the timer and trigger assembly. Another noticeable stressed spot was the mounting screw of the trigger assembly, which supported the setback force combining the scroll assembly and trigger assembly itself. In the case of a cracked sleeve, screw stress is released. On the other hand, if the sleeve is strong enough to keep its shape, the setback force acts on the trigger assembly in the direction pulling mounting screws out of sleeve threaded holes. This can be found from the three units tested at g levels from 21,750 to 29,088, all mounting screws appeared loose or unscrewed few turns.

   The consequence of sleeve deformation or trigger assembly separate from sleeve is the transfer of setback force to the SSD and support washer. As revealed by test samples F1 and F2, which had cracked sleeves, SSD's were hit by an impact force and damaged with bottom plate bent against rotor, jamming the mechanism; Support washers were buckled.

2. Heat treatment at 350° F, 4 hours for sleeve of Al. alloy 2014-T6 did not increase sleeve strength because this process was merely an extension of aluminum alloy precipitation heat treatment in transforming 2014-T4 to 2014-T6. For sleeve originally of 2014-T6, the artificial aging did not change alloy strength appreciably, however, heat treating of sleeve at 450° F, 4 hours overaged the alloy. Hardness test showed that the sleeve hardness was reduced and consequently lowered tensile strength but increased ductility. This was demonstrated by samples G1, G2 and G3 which were tested at incremental g levels of 28,000, 29,000 and 30,000. Sleeves appeared slightly necked down, distorted and seriously distorted respectively. But none of these units had a crack or fracture in stressed zones. This trade-in of strength to ductility may allow 2014-T6 sleeve applicable closely to the margin of 30,000 g .

3. The high g trigger arrangement changed the form of setback force distribution. The trigger spacer supported the total load at the shoulder of body I. D. The load was acting on the trigger spacer in the form of compression. The sleeve's wall and trigger assembly mounting screws were not the major stressed zones. As the trigger spacer was compressed under setback force, the load was transfered

to the SSD and support washer in a slower rate in comparison to the impact force exerted by suddenly broken sleeve as in the case of samples F1 and F2. Therefore an intact SSD was maintained at 30,000 g shooting.

E5. AIR GUN TEST REPORT

Date of Test: June 7, 1982 and June 18, 1982

Object: To evaluate parts strength at simulating g levels.

Configuration: Four groups of fuze samples as described in the following.

Procedures: Fuzes were assembled at BSIC production line. Sleeve hardness was measured and SSD timing was recorded before assembly. Inert fuzes were used. Air gun test was performed at Picatinny Arsenal test laboratory, at ambient temperature.

Test Result:

Group 1:- Three Bulova Sleeves of 7075-T6 bar stock machined to regular configuration and dimensions, assembled with HTI Support Washer and Body Plug (new design). Remainder was standard production hardware.

S/N	Sleeve BHN	Pretest SSD Timing	Testing g	After Test Part Conditions
1	152	1.23	25,340	Support Washer slightly wavy; SSD Top Plate intact, Bottom Plate deflected, Rotor functioning, timing 1.08; Sleeve in good shape; Trigger Spacer mounting screw (1) came out 3-4 turns, threads intact.
2	154	1.13	27,232	Support Washer wavy; SSD Top Plate intact, Bottom Plate deflected at the opening of spacer where the plate had no support, Rotor functioning, partially armed because it was hindered by deflected plate. Timing 0.74 sec; Sleeve good: Trigger Spacer screws (2) loosened 2 turns, (1) lost torque.

3	155	1.22	29,119	Support Washer distorted; SSD Top Plate coined, Bottom Plate deflected seriously especially at area without solid support, jammed both detents and rotor; Sleeve sheared off the base, at two tap holes and at bottom cutout; Trigger Bottom Plate slightly deflected. mounting screws (1) came out (2) loosened.

Group 2 :- Two Bulova Sleeves of 7075-T6 bar stock machined to regular dimensions, assembled with all Bulova standard parts.

S/N	Sleeve BHN	Pretest SSD Timing	Testing g	After Test Part Conditions
4	154	1.28	29,390	Support Washer good; SSD package squeezed, detents working, SSD not armed, rotor hindered but movable by force, coining on plate at opening, escapement and rotor pivot holes; sleeve intact; mounting screw (1) loosened two turns (2) lost torque.
5	154	1.25	32,311	Support Washer good; SSD not armed, package squeezed, rotor hindered, plate deflected at opening, coining on plate at opening and all pivot holes; sleeve intact with very slight neck; mounting screw (1) loosened two turns (1) lost torque.

Group 3 :- Two Bulova sleeves of 7075-T6 reclaimed from group 1 tested samples (Unit #1 was tested at 25, 340 g, Unit # 2 was tested at 27, 232 g), re-assembled with all standard Bulova parts.

S/N	Pretest SSD Timing	Testing g	After Test Part Conditions
1	1.20	30,012	Sleeve cracked at base but not separate; Support Washer good; SSD not armed, Rotor jammed, pivots coining into pivot holes of plate; (3) mounting screws lost torque.
2	1.27	29,826	Sleeve intact, in good shape; Support Washer good; SSD functioning arming time delay 1.23 seconds; mounting screws (1) screw loosened two turns, (2) screws lost torque.

Group 4 :- Three HTI sleeve assembled with HTI new designed support washer and body plug, remainder was Bulova standard part.

S/N	Sleeve BHN	Pretest SSD Timing	Testing g	After Test Part Conditions
87	142	1.17	30,673	Support Washer wavily deflected; SSD Bottom Plate bent at spacer opening, stopping rotor function; Trigger Assembly pulled away from sleeve with mounting screws loosened; sleeve slightly necked down at lower part.
88	145	1.04	22,322	Support Washer in good shape; SSD intact, functioning, arming delay 1.05 seconds, but interlock detent pin bent; Sleeve cracked, lower part separated; Trigger Assembly (2) screws came out (1) screw loosened.

89	142	1.15	30,695	Support Washer distorted seriously; SSD deflected badly with detents jammed, no function; Sleeve cracked and lower part separated; Trigger Assembly screws loosened.

Discussion

1. 7075-T6 sleeves had a strength to operate up to 27,232 g. There was no trace of deflection. At 30,000 gs, it was marginal. Of 5 sleeves tested at gs ranging from 29,119 to 32,311, 3 sleeves were intact. The remaining two units, one sleeve sheared off the base at tap holes and bottom cutout at g of 29,119, another cracked but not separate at base at g of 30,012 (this sleeve was tested twice, the first test used 25,340 g and the sleeve survived). Both units failed at the area of stress discontinuity where the material strength was greatly reduced.

2. Air Gun Test indicated that the HTI sleeves had inconsistent strength property. One unit survived 30,673 g, another failed at 30,695 g and the third failed at a low g level of 22,322 (note that in the third unit, the SSD and the Support Washer remained in good shape after test).

3. SSD assembled with regular Support Washer and Body Plug functioned margin-Ally at 30,000 g level. 3 out of 4 SSD tested at this g level appeared rotor hindered becuase of pivots coining into pivot holes on plates, therefore failed arming. ONE SSD survived 29,826 and functioned normally after test.

4. SSD assembled with HTI new designed Support Washer and Body Plug had a reduced strength. It functioned up to 25,340 g. None of the 4 Units tested at gs of 27,232, 29,119, 30,673 and 30,695 functioned normally. All of them appeared that bottom plates deflected (different extents) and hindered or jammed the rotor or detents,or both.

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